TABLE OF CONTENTS

List of Tables..............................iii 1/A7
List of Figures..............................v 1/A9
List of Appendices...........................v 1/A9
Foreward....................................vi 1/A10
Summary...................................viii 1/A12
Introduction.................................1 1/A13
Objective....................................2 1/A14
Experimental Approach........................2 1/A14
Flight Deck Data Collection..................3 1/B1
    Approach and Landing Procedures.......4 1/B2
    ATC Communications Workload
        by Phase of Flight............8 1/B6
    Overlapping Audio Signals and
        Voice Communications..........8 1/B6
Synthesizer Callout System (SYNCALL)..........11 1/B9
    System Design.........................11 1/B9
    Voice Message Design..................14 1/B12
Experimental Design...........................16 1/B14
Development of Performance Measures...........19 1/C3
    Percent Time Out of Tolerance.........20 1/C4
    Maximum Deviation.....................20 1/C4
    Mean Positive Deviation...............20 1/C4
    Mean Negative Deviation...............21 1/C5
Flight Performance Parameters.................21 1/C5
    Operational Airspeed Tolerance........22 1/C6
    Operational Sink Rate Tolerance.......22 1/C6
    Operational Localizer Deviation
        Tolerance.....................25 1/C9
    Operational Tolerance for Glideslope
        Deviations....................25 1/C9
Measures of Pilot Judgments of System
    Performance...........................28 1/C13
Procedure.....................................30 1/D1
Results.......................................33 1/D4
Flight Performance Results....................33 1/D4
    Analyses of Approaches Overall........34 1/D5
    Summary of 4-Way AOV's................42 1/D13
    Analyses of Individual Approaches.....43 1/D14
    Airspeed Deviations During Localizer
        Back Course Approach..........44 1/E1
    Sink Rate Deviations During the VOR
        Approach......................46 1/E3
    1-Engine Approach and Landing
        Performance...................48 1/E6
    Summary of Individual Approach
        Results.......................51 1/E9
SYNCALL and Pilot-not-Flying Callout
    Performance...........................43 1/D14
    Reliability of Callouts...............52 1/E10
    Relative Timing of Normal Callouts
        made by PNF and by SYNCALL....57 1/F1

Other Audio Information that Overlapped SYNCALL Callouts.......58 1/F2
Timing Accuracy of Ten-Foot Callouts by SYNCALL....................59 1/F3
Inappropriate Callouts by SYNCALL.....60 1/F4
Callouts Made by PNF but not by SYNCALL.....................60 1/F4
Summary of Callout Performance Data...65 1/F13
Pilot Judgment Data............................65 1/F13
Summary of Pilot Judgment Data........74 1/G9
Discussion....................................76 1/G11
Conclusion....................................78 1/G13
Refinement of a Synthesized Voice Callout System........................79 1/G14
SYNCALL System Components....................79 1/G14
Normal Altitude Callouts..............80 2/A3
Normal Position Callouts..............80 2/A3
Deviation Callouts....................80 2/A3
Critical Altitude Callouts............80 2/A3
Priority Logic........................81 2/A4
Callout Timing and Repetition Logic...82 2/A5
Tolerance Values......................83 2/A6
Summary of Recommended Changes to SYNCALL....................84 2/A7
Summary of Proposed Modifications to SYNCALL....................88 2/A11
References....................................89 2/A12

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Synthesized Voice Approach Callouts for Air Transport Operations

Carol A. Simpson

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Synthesized Voice Approach Callouts for Air Transport Operations

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National Aeronautics
and Space Administration

Scientific and Technical
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TABLE OF CONTENTS

List of Tables..............................iii
List of Figures...............................v
List of Appendices............................v
Foreward.....................................vi
Summary....................................viii
Introduction..................................1
Objective.....................................2
Experimental Approach.........................2
Flight Deck Data Collection...................3
    Approach and Landing Procedures.......4
    ATC Communications Workload by Phase of Flight............8
    Overlapping Audio Signals and Voice Communications..........8
Synthesizer Callout System (SYNCALL)..........11
    System Design.........................11
    Voice Message Design..................14
Experimental Design...........................16
Development of Performance Measures...........19
    Percent Time Out of Tolerance.........20
    Maximum Deviation.....................20
    Mean Positive Deviation...............20
    Mean Negative Deviation...............21
Flight Performance Parameters.................21
    Operational Airspeed Tolerance........22
    Operational Sink Rate Tolerance.......22
    Operational Localizer Deviation Tolerance....................25
    Operational Tolerance for Glideslope Deviations...................25
Measures of Pilot Judgments of System Performance...........................28
Procedure.....................................30
Results.......................................33
Flight Performance Results....................33
    Analyses of Approaches Overall........34
    Summary of 4-Way AOV's................42
    Analyses of Individual Approaches.....43
    Airspeed Deviations During Localizer Back Course Approach..........44
    Sink Rate Deviations During the VOR Approach.....................45
    1-Engine Approach and Landing Performance..................48
    Summary of Individual Approach Results......................51
SYNCALL and Pilot-not-Flying Callout Performance...........................43
    Reliability of Callouts...............52
    Relative Timing of Normal Callouts made by PNF and by SYNCALL....57

Other Audio Information that Overlapped SYNCALL Callouts.......58
Timing Accuracy of Ten-Foot Callouts by SYNCALL....................59
Inappropriate Callouts by SYNCALL.....60
Callouts Made by PNF but not by SYNCALL....................60
Summary of Callout Performance Data...65
Pilot Judgment Data...........................65
Summary of Pilot Judgment Data........74
Discussion......................................76
Conclusion......................................78
Refinement of a Synthesized Voice Callout System.........................79
SYNCALL System Components....................79
Normal Altitude Callouts..............80
Normal Position Callouts..............80
Deviation Callouts....................80
Critical Altitude Callouts............80
Priority Logic........................81
Callout Timing and Repetition Logic...82
Tolerance Values......................83
Summary of Recommended Changes to SYNCALL....................84
Summary of Proposed Modifications to SYNCALL....................88
References......................................89

LIST OF TABLES

Table 1. - Types of flight operations observed..........4
Table 2. - Mean Numbers of ATC changes During Descent and Approach..........5
Table 3. - Air Traffic Control Voice Communications Workload by Phase of Flight..........8
Table 4. - SYNCALL Triggering Conditions and and Wordings for Normal Callouts..........13
Table 5. - SYNCALL Triggerings and Callout Wordings for Deviation Callouts..........15
Table 6. - Examples of SYNCALL Callouts..........16
Table 7. - Approaches Flown for SYNCALL Evaluation......18
Table 8. - Experimental Design..........19
Table 9. - Semantic Differential Scales..........29
Table 10. - Types of Callouts Measured with Semantic Differential..........30
Table 11. - Introductory Passage by Speech Synthesizer...31
Table 12. - Sink Rate Performance for All Approaches During Segment II..........37
Table 13. - Airspeed Performance for All Approaches During Segment II..........37
Table 14. - (a & b) Airspeed Performance During Segment III..........39
Table 14. - (c & d) Sink Rate Performance During Segment III..........40
Table 15. - (a & b) Airspeed Performance During Segment IV..........42
Table 15. - (c & d) Sink Rate Performance During Segment IV..........43
Table 16. - Airspeed Performance for Localizer Back Course Approach During Segment IV.......45
Table 17. - (a & b) Number of Approaches Inside and Outside Tolerance for Airspeed During Localizer Back Course Approach..........48
Table 18. - Sink Rate Performance for VOR Raw Data Approach during Segment III..........49
Table 19. - Airspeed Performance for 1-Engine Approach and Landing..........50
Table 20. - Reliability of SYNCALL and PILOT-NOT-FLYING for Normal Callouts in the Simulator..........53
Table 21. - Reliability of PILOT-NOT-FLYING on the Line and in the Simulator for Normal Callouts..........54
Table 22. - Reliability of Normal Callouts by PILOT-NOT-FLYING on the Line and in the Simulator and by SYNCALL..........54
Table 23. - Reliability of Deviation Callouts by SYNCALL and PILOT-NOT-FLYING..........55
Table 24. - Reliability of Deviation Callouts by PILOT-NOT-FLYING with SYNCALL and with NO SYNCALL..........56
Table 25. - Reliability of Individual Normal Callouts by SYNCALL and by PILOT-NOT-FLYING in the simulator and on the Line..........57

Table 26. - Relative Timing of Normal Callouts by PILOT-NOT-FLYING and SYNCALL.................58
Table 27. - Percent of SYNCALL Callouts Overlapped with other Audio Information.................59
Table 28. - Percent of Pilots who wanted SYNCALL to Make Normal and Deviation Callouts for Four Types of Approach Conditions........66
Table 29. - Percent of Pilots who wanted PILOT-NOT-FLYING to Make Normal and Deviation Callouts for Four Types of Approach Conditions..................................67
Table 30. - Perceived Intelligibility of Speech Heard during SYNCALL Study...................70
Table 31. - Line Pilot Preferences for SYNCALL Deviation Callout Tolerances.. 71
Table 32. - Line Pilot Preferences for SYNCALL Deviation Callout Repetion Rates and Active Zones.................................71
Table 33. - Pilot Ratings of Their Own Suggested Modifications to SYNCALL.....................72

LIST OF FIGURES

1. - American Airlines DC-10 Approach Callout Procedures, Flight Manual, page 63, 2-27-75. Reprinted by permission.......7
2. - Experimental SYNCALL (Synthesized Approach Callout) System..........12
3. - Operational Tolerance: Airspeed..........23
4. - Operational Tolerance: Sink Rate..........24
5. - Operational Tolerance: Localizer..........26
6. - Operational Tolerance: Glideslope..........27
7. - Analysis of Variance Design for Approach Set I..........35
8. - Analysis of Variance Design for Approach Set II..........35
9. - Design for Analysis of Variance for Individual Approaches..........45
10. - Mean Airspeed Deviaitons for Localizer Back Course Approach..........47
11. - Altitude Error of Ten-Foot Callouts by SYNCALL as a Function of Sink Rate..........61
12. - Minimum Altitude Error by Sink Rate for Ten-Foot Callouts by SYNCALL..........62
13. - Mean Altitude Error by Sink Rate for Ten-Foot Callouts by SYNCALL..........63
14. - Maximum Altitude Error by Sink Rate for Ten-Foot Callouts by SYNCALL..........64
15. - Semantic Differential Ratings of Callouts by 14 Captains and 14 First Officers..........68
16. - Semantic Differential Ratings of the GPWS "Glideslope" and the GPWS "Whoop Whoop! Pull Up!" by 14 Captains and 14 first Officers..........69

LIST OF APPENDICES

A. - Altitude and Approach Callouts by Speech Synthesizer, paper prepared by Carol A. Simpson, National Research Council Associate, NASA Ames Research Center, April, 1976.

B. - Flight Scenario for One of Four Experimental Orders

C. - SYNCALL Debriefing Form

D. - Follow-up SYNCALL Debriefing Form

FOREWARD

This project owes its very existence to a unique combination of talents, resources, and dedication from numerous individuals. Neither NASA nor American Airlines could have undertaken the project alone, yet by their collaboration, the entire industry stands to benefit from the knowledge gleaned from this study. Dr. Robert C. Houston, Director-Technical Training Support for American Airlines and Captain J.A. (Al) Brown, then Director-Flying Training for American, saw the potential gain and supported the project throughout its course with whatever was needed that could be accomplished by AAL. For NASA, first Dr. Edward M. Huff as Chief of the Man-Machine Integration Branch and Thomas E. Wempe as Director of the Flight Management Program there made certain that the NASA contribution could be realized. Later, Dr. Alan B. Chambers, Chief of the Man-Vehicle Systems Research Division, gave the project his full support. The initial contact between NASA and AAL grew from pioneering work done by Drs. Charles Billings and John K. Lauber of the Aviation Safety Reporting Program at NASA. Special thanks to Captain Jay Theder and Charles Coulter of Allied Pilots Association for their review of the project and support throughout. H. J. Bell and Jessel V. Williams, FAA Principle Operations Inspector for American Airlines, at the Federal Aviation Administration Air Carrier District Office in Euless, Texas, gave their full support to the project, agreeing to the incorporation of the SYNCALL system into the normal recurrent training curriculum on an experimental basis. And Captain Al Reeser, Assistant Vice President-Training and Procedures, as skeptic and our most relentless critic was our strongest supporter in disguise.

The software used to edit and test the coding for the callouts themselves was developed by Lon Radin and Robert R. Krones of Informatics, Inc., in record time. The software that turned the SYNCALL design into a working system in the flight training simulator was the creation of Gene Tomlinson, Specialist-Flight Simulator Design, of AAL Simulator Support. Without his dedication to the project and the constant support of Joe DePaola, Manager-Simulator Support, SYNCALL would never have left the drawing boards. Captain Walt Estridge as Director of Flying Instruction melded together flight training requirements and the proposed experimental design into a workable set of maneuvers. Colby Noyes, Instructor Pilot, then turned this into a realistic scenario that could be used to fulfill recurrent training requirements without compromising the balanced experimental design. Instructor Pilots Captain L.W. (Wes) King, Captain George A. Mitchell, Lou Britton, and Colby Noyes went above and beyond the call of duty to ensure the successful performance of the experimental procedure. The spirit they brought to the dual task of instructing and playing the role of air traffic controller added much to the realism of the simulation. And their comments, based on continued exposure to the system over the course of the experiment were invaluable to the interpretation of the data. Throughout the course of the study Captain George Hazelhurst, Chief Pilot for DC-10 Flight Instruction gave his full support to

coordinating the input from instructor pilots, crew scheduling, and final check-out of the experimental SYNCALL system. Captain George Hoff and Captain Bob Cornelison, each as Chief Pilot-San Francisco facilitated arrangements for the wide range of flight deck observation flights. And without the enthusiastic help of Captain Frank Nehlig, Chief Pilot-Los Angeles, the study would not have included realistic ATC background audio. James Marigliano (AAL) literally worked miracles with crew schedules to ensure that each session had a complete three-man crew. Once the data had been collected, the massive task of analysis could not have been completed in several years time without the help of Libby Stager, Chris Wagenet, William Hardy, and Donna Miller at the Ames Research Center.

Final thanks goes to the pilots and flight engineers who flew SYNCALL and gave the project the benefit of their combined thousands upon thousands of hours of experience flying the line and to the many many pilots who enthusiastically shared their flight deck and their ideas on cockpit warning system design, present and possible future. Without their help, instruction, and ideas this project could not have happened.

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This paper is dedicated to Dr. H.P. (Pat) Ruffle-Smith. To each of you who played an essential role, thank you.

Carol A. Simpson
October 23, 1979

SUMMARY

A flight simulation experiment was performed to determine the effectiveness of synthesized voice approach callouts for air transport operations. Flight deck data was first collected on scheduled air carrier operations to describe existing pilot-not-flying callout procedures in the flight context and to document the types and amounts of other auditory cockpit information during different types of air carrier operations. A flight simulation scenario for a wide-body jet transport airline training simulator was developed in collaboration with a major U.S Air Carrier and flown by three-man crews of qualified line pilots as part of their normally scheduled recurrent training. Each crew flew half their approaches using the experimental synthesized voice approach callout system (SYNCALL) and the other half using the company Pilot-not-Flying approach callout procedures (PNF). Airspeed and sink rate performance was better with the SYNCALL system than with the PNF system for non-precision approaches. For the One-Engine Approach, for which SYNCALL made inappropriate deviation callouts, airspeed performance was worse with SYNCALL than with PNF. Reliability of normal altitude approach callouts was comparable for PNF on the line and in the simulator and for SYNCALL in the simulator. However, SYNCALL was more reliable than PNF for making deviation approach callouts in the simulator. Pilots generally favored the concept of SYNCALL and judged it more reliable than PNF callouts. They suggested modifications before it would be appropriate for operational use. It was concluded that SYNCALL improved flight performance for non-precision approaches, and that a SYNCALL system should make deviation callouts only. For consistency, it is recommended that the modes of the Ground Proximity Warning System (GPWS) be incorporated into a SYNCALL system. The detrimental effects on performance associated with inappropriate deviation callouts led to the further conclusion that such callouts should be designed out of the system. Finally, the results and conclusions of the experiment are used to develop suggestions for improvements to SYNCALL before further testing.

SYNTHESIZED VOICE APPROACH CALLOUTS FOR AIR TRANSPORT OPERATIONS

Carol A. Simpson

INTRODUCTION

The final approach and landing segment of jet transport operations requires exact and constant awareness by the crew of altitude and position. This information is currently provided in visual form by the flight instruments and in spoken form by callouts made by whichever pilot is not actively flying the approach. Airline procedures call for the pilot-not-flying to monitor the performance of the pilot-flying by scanning the flight instruments and calling out specific altitudes and any observed deviations outside company-prescribed tolerances. Prior to the point where the pilot-flying expects to be able to see the runway, one pilot (depending on the airline) begins looking outside and reports when the runway is in sight. The other pilot focuses visually inside the cockpit and monitors the flight instruments. This pilot and, in some cases, the flight engineer are then responsible for making the necessary approach callouts. The specific set of callouts used and assignment of responsibility for making the callouts to pilot-not-flying and/or to the flight engineer varies somewhat across air carriers. Despite some differences in the choice of callouts, the intended functions of the callouts are common to all carriers. These are 1) to reduce the visual workload for the pilot-flying, 2) to keep all three crewmembers aware of aircraft altitude and position, and 3) in the case of callouts that require acknowledgment from the pilot-flying, to serve as a check for incapacitation of the pilot-flying.

In the discussion that follows, the term "pilot-not-flying callouts" will stand for all of the approach callouts regardless of which crew member is actually expected to make particular callouts. This will permit discussion of the approach callouts themselves without referring to the differences among air carriers.

A number of air carrier approach and landing accidents during low or impaired visibility have been associated with the absence of approach callouts. This fact at first suggests that the absence of altitude and deviation callouts may have contributed to inadvertent flight into terrain during these approaches. Such a conclusion was drawn by the National Transportation Safety Board in a special study on flight crew coordination procedures in accidents during air carrier instrument landing system approaches. (1) However, due to the absence of data on callout performance for successful approaches made during the same period (1970-1975) no test of this suggested relationship of cause and effect can be performed.

Another untestable post hoc hypothesis is that increased workload during the approaches that terminated in accidents prevented the pilot-not-flying from making the callouts. While neither hypothesis can be directly tested, it is reasonable to ask whether the current procedure can be improved, especially when unexpected events cause a high workload in the cockpit. One alternative medium for information transfer would be a speech synthesizer which could receive raw data from the onboard central air data computers and automatically make the callouts at appropriate times during the approach.

OBJECTIVE

The purpose of the present study was to compare a pilot-not-flying (PNF) approach callout system to a system composed of PNF callouts augmented by an automatic synthesized voice callout system. A full task flight simulation experiment was conducted to determine if one or the other system transfers altitude and deviation information more reliably than the other and/or results in better flight performance by the pilot-flying.

EXPERIMENTAL APPROACH

This objective was accomplished by a collaborative effort between American Airlines Flight Academy and NASA Ames Man Vehicle Systems Research Division. A DC-10 flight training simulator was flown during normal flight training using crews as assigned but on a strictly voluntary basis. All pilots offered the opportunity to participate did so. Twenty 3-man crews flew several types of approaches half with the standard callout procedures and half with a synthesized voice callout system (SYNCALL). Measurements were made of flight performance, callout reliability, callout interference with other audio events, and pilot ratings of callouts on several scales.

The experimental approach actually incorporated two types of data collection: 1) Flight Deck data collection and 2) data collection during the formal flight simulator experiment comparing pilot-not-flying callouts to SYNCALL callouts.

FLIGHT DECK DATA COLLECTION

Design of an automatic approach callout system and measurement of the effectiveness of approach callouts in the flight context in a way that is meaningful for airline flight operations requires some degree of familiarity with flight operations and the complex environment in which those operations take place. The author did not at the onset of the project, have the requisite familiarity with multi-engine jet transport airline operations. Thus the first phase of the project was a program of flight deck observation by the author. The necessary authorizations from the air carrier and the Federal Aviation Administration (FAA) were issued for "the purpose of observing flight crew activity to gain insights into the potential uses and pitfalls for synthesized speech."

A systematic approach was taken for the flight deck observation program. The program goals were:

1) To gain over-all familiarity with airline flight operations and the tasks performed during each phase of the flight by each crew member and to observe interactions among crew members,

2) To collect data on time spent with voice communications with ATC as a function of phase of flight. This was needed in order to assess the possibility of simultaneous voice messages from ATC and a synthesized voice callout system.

3) To collect data on the frequency of and type of occurrences of simultaneous or overlapping voice messages from multiple sources and to observe the methods used by the crew to cope with such situations;

4) To become familiar with the existing pilot-not-flying approach callout procedures as a function of type of weather, type of approach, and pilot flying;

5) To observe any instances in which pilot-not-flying callouts were not made to determine possible reasons for each such instance, e.g. distraction from ATC, higher than normal or different from normal workload for the pilot-not-flying, intentional omission of certain callouts due to approach circumstances, etc;

6) To collect the above data for a cross section of type of flight operations - long, cross-continental, short haul, overwater, night, day, large or small airport, high or low traffic density, type of approach;

7) To have an opportunity to observe instances of the crew performing other than normal operations. Since abnormal or emergency operations are extremely rare, a large number of observation flights was needed in order to obtain any such instances.

8) To collect crew preferences for the possible uses of synthesized speech in the cockpit while they were in the actual cockpit environment. [1]

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[1]. Such conversations were conducted only during the cruise

Approach and Landing Procedures

The following narrative description of crew approach and landing procedures is based on the author's experience and data collected for a sample of flights or "trip legs" during which scheduled air carrier operations were observed from the "jump seat" directly behind the captain's seat. Table 1 lists the types of aircraft and flight operations that were observed. The flight crew was observed to be a close-knit team with each member performing certain functions. Throughout the approach the crew members must use a certain amount of judgment in planning when to carry out their tasks so as to complement rather than interfere with each other. The approach callouts are only a part of the procedures carried out during the approach to landing and as such will be described in this context.

TABLE 1. TYPES OF FLIGHT OPERATIONS OBSERVED

NUMBER OF FLIGHTS	72
NUMBER OF DIFFERENT AIRPORTS	24

AIRCRAFT TYPES:	
727	30
707	16
DC-10	18
747	8

TRIP DURATION:	
< 1 HR	5
1 - 2 HRS	21
2 - 3 HRS	13
3 - 4 HRS	19
> 4 HRS	14

TIME OF DAY:	
DAY	51
NIGHT	21

TYPE OF OPERATION:	
DOMESTIC PASSENGER	66
OVERWATER PASSENGER	2
DOMESTIC FREIGHT	4

Throughout the entire flight the captain and the first officer are responsible for flying the aircraft with the captain having final decision-making authority as pilot-in-command. Typically, the captain and first officer alternate "legs" actually flying the aircraft so that each pilot receives time at the flight controls. So, for a given approach one of the pilots will fly the aircraft, either manually or using one of several autopilot modes. The other pilot communicates by voice over the radio with the ground-based air traffic controllers.

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segment of the flight and only at the convenience of the crew and with the Captain's permission. Ongoing conversations were halted immediately, often in mid-sentence, whenever any flight duty, such as communication with ATC, was required.

The Flight engineer, in addition to his primary responsibilities as the aircraft systems operator, is usually delegated additional monitoring and communications responsibilities. During Take-Off and Landing he serves as a back-up for the two pilots to double-check that checklist items are performed.

The flight engineer's back-up function is particularly important during the approach to landing since the pilots are busy with frequent changes in ATC communications and navigation frequencies, and aircraft heading, airspeed, and altitude. Table 2 lists the observed average numbers of such changes that were given to the crew by ATC per descent and approach. In addition to complying with instructions from ATC, the pilots must make other changes in heading, altitude, airspeed, and aircraft configuration in order to follow their desired flight route to runway touchdown.

TABLE 2. MEAN NUMBERS OF ATC CHANGES DURING DESCENT & APPROACH FOR 30 SCHEDULED AIR CARRIER FLIGHTS ACROSS FOUR AIRCRAFT TYPES AND SIXTEEN AIRPORTS

	mean	sd
Segment Time (Beginning of Descent to Landing) (min)	24.0	7.5
Number of Heading Changes	2.6	1.8
Number of Altitude Changes	5.3	1.3
Number of Frequency Changes	4.1	1.1
Number of Speed Changes	1.8	1.7
TOTAL Number of Changes	13.8	

Preparation for the approach begins while still at cruise altitude. The flight engineer tunes his communications radio to the frequency on which the Automatic Terminal Information Service (ATIS) broadcast is being transmitted. He copies down the information on winds, runways in use, and approaches to be expected. He then re-copies the information onto a prepared form and passes it forward to the pilots. Once the pilots have this information, they can plan the approach. They select the appropriate approach charts and review the flight profile in terms of altitudes, navigational fixes, distances, headings, navigational aid frequencies, and missed approach procedures. The captain gives any special instructions warranted by the particular conditions.

The approach segment, which has been defined here as starting when the ATC approach controller clears the aircraft for the approach, usually starts at approximately 3000 feet Above Field Level (AFL) and includes interception of the final approach course, passage over a final approach fix, and descent down the desired glidepath to touchdown on the runway. All of the Approach Callouts are made during this segment, which lasts some 8 to 10 minutes. Thus this segment was chosen for the comparative study of the two callout systems.

Figure 1 is a reproduction of the page in the airline's flight manual describing the approach callouts. During the course of the approach the pilot-flying must intercept the final approach course and descend to the runway touchdown point at the necessary rate so as to maintain the desired glidepath. Tracking of the glidepath may be accomplished either by reference to raw data such as time, speed, and rate of descent or by reference to a ground-transmitted glideslope signal. If the latter is available, the approach is classified as a precision approach, and the approach can be flown to a relatively lower altitude and with less visibility than is possible without a glideslope signal. If a glideslope signal is not available, then that approach is called a non-precision approach. Either type of approach can be flown using what is called "raw data" or using command data from a "Flight Director". The data provided directly by the flight instruments is called "raw data". The Flight Director, on the other hand, processes the raw data and provides maneuvering commands via steer and pitch bars or needles or similar display, depending on the aircraft. With a Flight Director, the pilot flies according to the steer and pich commands on the display.

For either type of approach, there is a minimum altitude to which the aircraft is permitted to descend without having the runway in sight. In the United States, this is called Minimum Descent Altitude (MDA) for non-precision approaches and Decision Height (DH) for precision approaches. If the runway is in sight by the time the minimum altitude is reached and if the pilot-flying judges that the landing is assured, then the approach is continued to landing (or go-around, should the situation subsequently become unfavorable for landing). There is a further detail in the case of non-precision approaches, those using an MDA. For these there is also a Missed Approach Point (MAP) at a specified point on the final approach course. If at MDA the runway is still not in sight, the aircraft can be flown at MDA altitude until the MAP is reached, descending to landing if the runway is acquired visually. Upon reaching the MAP with no runway in sight, the crew makes a go-around.

During the approach the pilot-not-flying monitors the approach, operates the slats, flaps, and landing gear as desired by the pilot-flying, and prepares mentally to make a go-around if necessary. He makes the normal approach callouts applicable to the particular type of approach being flown, as indicated in Figure 1. And, if deviations occur in airspeed, sink rate, localizer, or glideslope, he calls these to the attention of the pilot-flying.

The Flight Engineer finishes the "Before Landing Checklist"

NORMAL PROCEDURES

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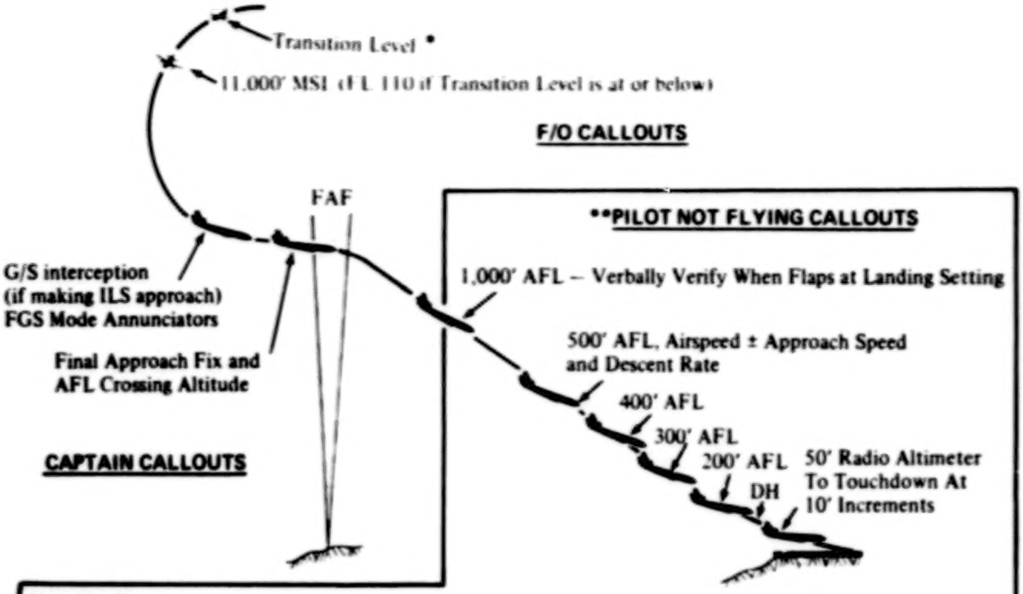
DC-10 Operating Manual

Section 3 **Page** 63

2-27-76

STANDARD CALLOUTS – ALL DESCENTS, APPROACHES AND LANDINGS


Transition Level *
11,000' MSL (FL 110 if Transition Level is at or below)
F/O CALLOUTS
FAF
**PILOT NOT FLYING CALLOUTS
1,000' AFL – Verbally Verify When Flaps at Landing Setting
500' AFL, Airspeed ± Approach Speed and Descent Rate
400' AFL
300' AFL
200' AFL
DH
50' Radio Altimeter To Touchdown At 10' Increments
G/S interception (if making ILS approach) FGS Mode Annunciators
Final Approach Fix and AFL Crossing Altitude
CAPTAIN CALLOUTS

Pilot Not Flying

Airspeed – With Landing Flaps anytime speed varies from approach speed by more than ±5 Kts.

Rate of Descent –	When Below:	If Descent Rate Exceeds:
	2,000'	2,000 FPM
	1,000'	1,000 FPM
	300'	700 FPM

During Cat II Approaches F/O will make all callouts from 500' to landing, including Airspeed or Descent Rate if not within limits.

LOC and GS indication Callout – On final, anytime any crewmember observes LOC displacement greater than 1/3 dot and/or G/S displacement greater than 1 dot, other pilot will acknowledge this deviation.

NOTES:

1. Use the Captain's or F/O's altimeter for all altitude callouts, except for the CAT II approach, in which case use the radio altimeter for the 300' callout and remaining callouts below 300' to touchdown.
2. When executing a non-precision approach, the pilot not flying will call out "100' ABOVE MDA," MDA and MAP.
3. Callouts not applicable on non-precision or visual approaches should be disregarded.

* For Transition Level outside U.S. refer to avigation charts.

F/E MONITORING

In addition to his normal monitoring of engine instruments and F/E panel, the F/E will monitor flight instruments, especially altitude and airspeed. He will assist in maintaining a watch for traffic and other factors that could adversely affect safety. He will monitor HSI and ADI navigation indications and call out any discrepancies between the two instruments. On final, call out LOC displacement anytime it is greater than 1/3 dot and/or G/S displacement anytime it is greater than 1 dot.

Figure 1. - American Airlines DC-10 Approach Callout Procedures, Flight Manual, page 63, 2-27-76. Reprinted by permission.

to ensure that all systems are set for landing or, where appropriate, armed for go-around. He assists the Pilot-not-Flying with the monitoring of the approach.

Since this entire segment lasts only some 8 to 10 minutes, it should be apparent that there is a fair amount of intra-cockpit voice communication that occurs in a short time, along with the ATC communications.

ATC Communications Workload by Phase of Flight

It was found that the amount of time used by the crew to communicate with ATC varied as a function of phase of flight. Correspondingly, so did the number of ATC transactions (consisting of one exchange between pilot and controller of either 1) pilot transmission to controller + controller acknowledgement or other response, or 2) controller transmission to pilot + pilot acknowledgement or other response). Table 3 lists this data.

TABLE 3. AIR TRAFFIC CONTROL VOICE COMMUNICATIONS WORKLOAD BY PHASE OF FLIGHT. MEANS FOR 39 TRIPS. STANDARD DEVIATIONS IN PARENTHESES.

	PHASE OF FLIGHT					
	TAXI	CLIMB	CRUISE	DESCENT	TAXI	TOTAL
SEGMENT DURATION (min)	19.68	24.77	86.68	25.61	5.58	163.41
(S.D.)	(12.33)	(11.48)	(71.55)	(11.72)	(3.66)	(76.41)
TIME TALKING/ LISTENING (min)	1.45	2.83	4.30	3.90	0.47	13.58
(S.D.)	(1.63)	(1.44)	(3.47)	(1.88)	(0.50)	(5.50)
PERCENT OF TIME SPENT W/ ATC	7 %	11 %	5 %	15 %	8 %	8 %
NO. OF ATC TRANSCACTIONS	9.25	17.29	21.81	20.89	2.87	70.05
(S.D.)	(4.09)	(8.34)	(17.31)	(8.99)	(2.60)	(23.55)
MEAN TIME PER TRANSACTION (s)	8.65	8.86	12.55	11.84	9.06	11.70
(S.D.)	(6.00)	(3.21)	(6.48)	(5.09)	(6.42)	(3.46)

Overlapping Audio Signals and Voice Communications

The types of situations in which overlapping of audio signals and/or speech communications occurred can be classified as either routine or unexpected. That is, certain combinations of overlapping audio occur on nearly every flight, necessitating either formal or informal crew procedures for handling them. Others occur occasionally by chance and must be handled by the crew on an event-specific and unique basis.

Many of the routine pairs of overlapping audio signals involve concurrent voice communications between 1) pilot-not-flying and ATC and 2) Flight Engineer and AIRINC (Aeronautical Radio Incorporated) or Company. Some examples are: 1) ATC Push-back or Taxi Clearance and Flight Engineer Time Out Report, 2) Initial ATC transaction with Departure Control and Flight Engineer's Time Off and Load Report, 3) Initial Descent from Cruise Clearance and F/E Monitor the ATIS, 4) Outer Marker Passage with Captain's Callout and Pilot-not-Flying contact Tower. Except for the last pair, the need for concurrent audio signals is handled routinely by assigning the ATC communications tasks to the Pilot-not-Flying and the AIRINC and Company Communications tasks to the Flight Engineer. However, in the case of the Outer Marker Callout by the Captain and the Pilot-not-Flying ATC call to the Tower, it happens that 50% of the flights involve the Captain and the Pilot-not-Flying being one and the same individual. This individual must then sequence the two voice messages, with the result that one or the other may be late. When the First-Officer is the Pilot-not-Flying, he may be calling the Tower at the same time as the Captain is making the Outer Marker Callout, with the result that he may not verbally process the callout; The Captain can and was observed to delay the callout until after contact with the tower had been established (duration of approx 8 s during which the aircraft descends another 136 feet at, say 1000 FPM). Thus, the First Officer as pilot-flying on these occasions will see an altimeter reading that could be as much as 100 feet different from that which the Captain as pilot-not-flying calls out. Types of overlapping auditory messages that occurred by chance included SELCAL or CABIN CALL bells or chimes overlapping with ATC communications or with crew cockpit voice communications. The Gear Warning Horn, which was observed to trigger several times per flight inappropriately, sometimes overlapped ATC communications or crew checklist callouts. Crew members handled these situations by sharing the workload, i.e. the Flight Engineer would respond to SELCALL or CABIN CALL while the pilot-not-flying would respond to the ATC transmission. There were instances when the pilot-not-flying requested a repetion of the message from the controller. There were also instances when the Flight Engineer delayed his response to the CABIN CALL until after completing his other verbal transaction, say reporting observed winds aloft to the company.

There were occasional instances of individual approach callouts omitted when they would have overlapped with other voice communications. On one flight, for example, the controller advised the crew of men and equipment beside the runway when the aircraft was at 300 feet AFL. The 300-foot callout was not made in this instance although other hundred foot-foot callouts were made.

Occasionally certain ten-foot callouts were systematically omitted by the PNF when the sink rate during flare was relatively higher. The PNF was observed to call "50, 30, 10". This seemed to convey the added information about the higher than average sink rate to the pilot-flying.

There were no approaches observed for which no callouts were made. Rather, individual callouts were systematically omitted according to specific circumstances of the approach. But in these cases, prior and succeeding callouts were made.

SYNTHESIZER CALLOUT SYSTEM (SYNCALL)

Figure 2 shows the experimental SYNCALL system designed to test the concept of automatic approach callouts. This system was designed to include all of the types of automatic approach callouts that might be useful. As such it was an experimental tool rather than a prototype system.

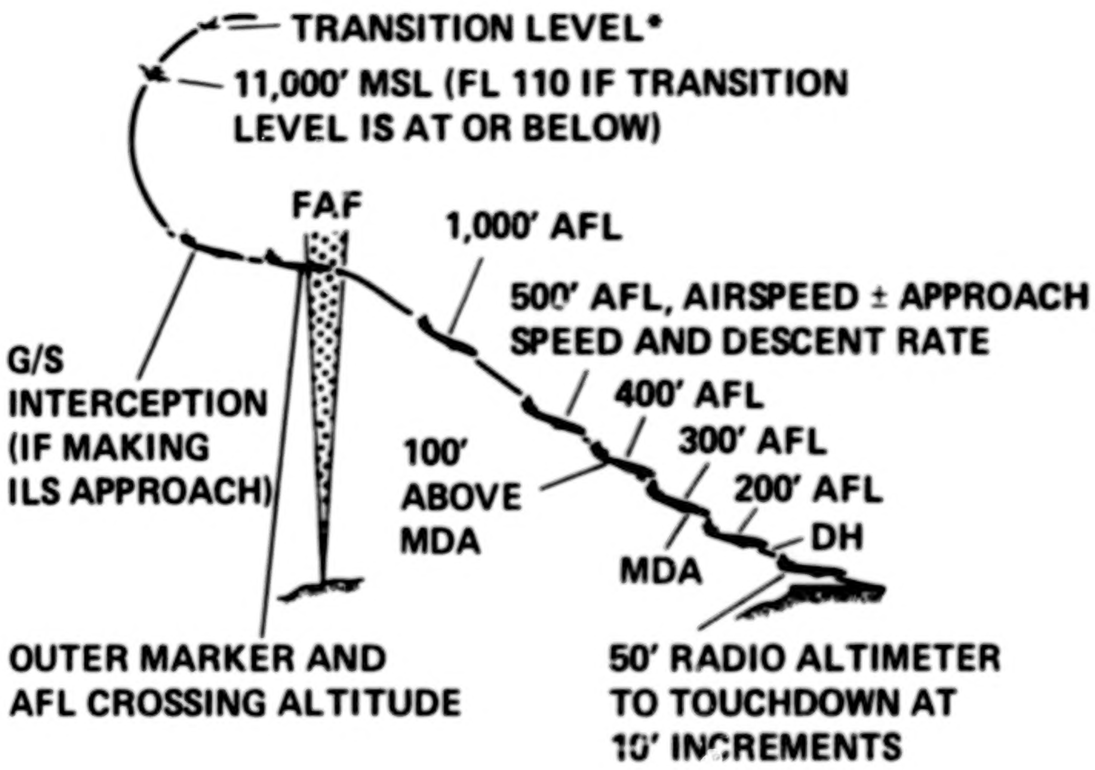
System Design

The synthesizer was programmed to make both normal and deviation callouts. The normal callouts were the standard callouts then required for all approaches by the participating airline. Table 4 lists the normal callouts made by the SYNCALL system with the flight condition that triggered each callout listed in the left column and the wording of each corresponding callout in the right column. A given normal callout was spoken by SYNCALL only once for a given approach. Also, if SYNCALL detected that it would deliver a normal callout within +/-50 feet of the altitude at which a Decision Height callout, a 100 feet above MDA callout, or an MDA callout was to be made or had been made, it supressed that normal callout.

The SYNCALL system was programmed to make deviation callouts only if glideslope deviation, localizer deviation, airspeed, or sink rate deviated beyond the tolerances that the Pilot-not-Flying is required to use for PNF deviation callouts. For example, the Pilot-not-Flying and the F/E were required to call deviations of +/-5 KTS or more deviation from the selected approach airspeed. The SYNCALL system was programmed to make an airspeed deviation callout if the deviation reached +/-7 KTS. The SYNCALL system was designed with larger tolerances so that it would serve as a back-up on deviation callouts for both the PNF and the F/E rather than functionally replacing these two crew members for the deviation monitoring and callout task. This was done because it was feared that the PNF and F/E might not monitor the flight instruments often enough or be left out of the information loop if the SYNCALL deviation callouts were not designed to give them first chance to detect any deviations. Table 5 lists the deviation callouts with the flight conditions that triggered them on the right and the callout wordings on the left.

It will be noted that some of the modes for the Ground Proximity Warning System (GPWS) coincide with conditions that would normally trigger deviation callouts by the SYNCALL system, cf. "Glideslope" for 1.3 dots or more below the glideslope. In order to avoid the aural confusion of concurrent voice messages from different sources but stating the same message, the aural warning of the GPWS was disabled when the SYNCALL system was in use. The SYNCALL system was programmed to perform all of the relevant GPWS callouts in addition to the deviation callouts that are not made by the GPWS system. In the case of simultaneously occurring demands for two or more deviation callouts, the callouts were made in sequence. The priority assignment from highest to lowest

SYNCALL APPROACH CALLOUTS


TRANSITION LEVEL*
11,000' MSL (FL 110 IF TRANSITION LEVEL IS AT OR BELOW)
FAF
1,000' AFL
500' AFL, AIRSPEED ± APPROACH SPEED AND DESCENT RATE
G/S INTERCEPTION (IF MAKING ILS APPROACH)
400' AFL
300' AFL
100' ABOVE MDA
200' AFL
DH
MDA
OUTER MARKER AND AFL CROSSING ALTITUDE
50' RADIO ALTIMETER TO TOUCHDOWN AT 10' INCREMENTS

DEVIATION CALLOUTS

AIRSPEED – BELOW 600 AFL, APPROACH SPEED ±7 kt

RATE OF DESCENT – BELOW 600 AFL 1200 fpm
BELOW 300 AFL 1000 fpm

LOCALIZER – ± 1/2 DOT

GLIDESLOPE – ± 1–1/3 DOT

Figure 2. - Experimental SYNCALL (Synthesized Approach Callout) System.

TABLE 4. SYNCALL CALLOUT TRIGGERING CONDITIONS AND CORRESPONDING CALLOUT WORDINGS FOR NORMAL CALLOUTS

TRIGGERING CONDITION	CALLOUT WORDING
Glideslope Interception	GLIDESLOPE INTERCEPT
Localizer Interception	LOCALIZER INTERCEPT
5 s after Outer Marker Triggering	OUTER MARKER (----) ABOVE FIELD
Descending Through 1000 ft AFL	ONE THOUSAND FEET ABOVE FIELD
Descending Through 500 ft AFL	FIVE HUNDRED FEET. AIRSPEED (+/- ----), SINK IS (----)
Descending Through 400 ft AFL	FOUR HUNDRED
Descending Through 300 ft AFL *	THREE HUNDRED
Descending Through 200 ft AFL	TWO HUNDRED
Descending Through 100 ft AFL	ONE HUNDRED
Descending Through DH Setting on Radio Altimeter and Setting < or = 250 ft	DECISION HEIGHT
Descending Through 100 feet Above Radio Altimeter DH Setting & Setting > 250 ft	ONE HUNDRED FEET ABOVE MDA
Descending Through DH Setting on Radio Altimeter and Setting > 250 ft	MDA
Descending Through 50 ft Radio Altimeter	FIFTY
" 40 ft Radio Alt.	FORTY
" 30 ft "	THIRTY
" 20 ft "	TWENTY
" 10 ft "	TEN

KEY: (----) refers to a specific value spoken by SYNCALL
e.g. "Five Hundred Feet, Airspeed + 10, Sink is 800."
DH Decision Height
MDA Minimum Descent Altitude

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* Note: Theoretically, when the Autoland Mode of the autopilot was engaged, indicating a Category II Approach, SYNCALL monitored the Radio Altimeter for altitude information from 300 feet to touchdown. Otherwise SYNCALL monitored Barometric Altitude from the Captain's Altimeter, which was set to Altitude Above Field Level (AFL) until 100 feet. This was in

accordance with airline procedure to eliminate erroneous AFL altitude readouts due to uneven terrain on final approach.

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was GPWS mode 2a or 2b (Excessive Terrain Closure), glideslope, indicated airspeed, sink rate, and localizer. A given deviation callout was spoken only once. If, however, the out-of-tolerance condition had not been corrected after a specific time lag, the deviation callout was repeated. This time lag was 5 s for the glideslope, airspeed, and sink rate deviation callouts and 10 s for the localizer deviation callouts. For airspeed and sink rate deviation callouts, a repetition was triggered after the time lag if the deviation was still out of tolerance. For localizer and glideslope deviation callouts, a repetition was triggered only if after the lag the aircraft was not closing on the desired in-tolerance window, i.e. only if the deviation was of the same magnitude or greater than it had been when the previous deviation callout was triggered. This type of repetition logic was designed because it takes time for the aircraft to respond to the pilot's control input to correct flight path deviations in glideslope and localizer. As long as the flightpath was in the process of being corrected, the SYNCALL system made no repetitions of the deviation callout, so as to reduce nuisance callouts.

Voice Message Design

The wording of the voice messages was selected so as to adhere as much as possible to the phraseology used by the crew for the approach callouts while applying previous research on voice warning message wording (2) to ensure high intelligibility even with competing human speech messages. Table 6 lists the wordings for each type of SYNCALL approach callout. These wordings were then tested for intelligibility under conditions that were more difficult than any expected to occur in a real cockpit. (See Appendix A)

TABLE 5. SYNCALL CALLOUT TRIGGERINGS AND CORRESPONDING CALLOUT WORDINGS FOR DEVIATION CALLOUTS

TRIGGERING CONDITION	CALLOUT WORDING
After G/S Capture, if A/C >/= 1 1/3 dots above Glideslope	YOU'RE ABOVE THE GLIDESLOPE
Same as Above, except A/C same amount below Glideslope (=GPWS Mode 5)	YOU'RE BELOW THE GLIDESLOPE
After Localizer Capture, if A/C >/= 1/2 dot right of Localizer	YOU ARE RIGHT OF THE LOCALIZER
Same as Above, except A/C same amount left of Localizer	YOU ARE LEFT OF THE LOCALIZER
A/C Below 600 ft AFL and Indicated Airspeed > or = 7 kts above Approach Speed Setting of Autothrottle System	AIRSPEED PLUS (----)
Same as Above, except Indicated Airspeed is > or = 7 kts below Approach Speed Setting	AIRSPEED MINUS (----)
If 600-300 AFL & Sink > 1200 fpm or If < 300 AFL & Sink > 1000 fpm	SINK IS (----)
GPWS Mode 2a or 2b Triggered	WHOOP WHOOP PULL UP

KEY: (----) refers to a value spoken by SYNCALL e.g. "Sink is 1300."

Notes: Deviation Callout repetition rate if condition not corrected = 5 s for Glideslope, Airspeed, and Sink Rate and 10 s for Localizer. Callout Priority from highest to lowest was GPWS Mode 2a or 2b (Terrain Closure), Glideslope, Airspeed, Sink Rate, Localizer.

TABLE 6. EXAMPLES OF SYNCALL CALLOUTS

LOCALIZER INTERCEPT
GLIDESLOPE INTERCEPT
OUTER MARKER 1480 ABOVE FIELD
1000 FEET ABOVE FIELD
500 FEET, AIRSPEED +4, SINK IS 1300
500 FEET, ON SPEED, SINK IS 1200
400
300
200
100
100 FEET ABOVE MDA
MDA
DECISION HEIGHT
50
40
30
20
10
YOU'RE ABOVE THE GLIDESLOPE
YOU'RE BELOW THE GLIDESLOPE
YOU ARE LEFT OF THE LOCALIZER
YOU ARE RIGHT OF THE LOCALIZER
AIRSPEED MINUS SEVEN
AIRSPEED PLUS NINER
SINK IS FIFTEEN HUNDRED
WHOOP WHOOP PULL UP

EXPERIMENTAL DESIGN

In order to study and evaluate the concept of an automatic approach callout system using synthesized speech, the experimental SYNCALL system was compared to a current airline system of approach callouts by the crew - referred to here as PNF callouts. For the data to be representative of the range of approach conditions encountered in the operational environment, several types of approaches, varying in crew workload and amount of manual flight control, were flown both by captains and first officers. For each type of approach, data was collected for each crew for both the SYNCALL and PNF approach callouts for both captains and first officers as the pilot flying.

So as to obtain representative user-pilot performance and judgment data, current line pilots, i.e. regular airline pilots who routinely fly the aircraft, served as participating pilot-subjects. The experimental sessions were incorporated into the airline's normal recurrent training that is required periodically for air transport pilots. The crew members involved in the study and the Federal Aviation Administration were given a guarantee that participation in this experimental study would in no way be allowed to jeopardize a crew member's training in required maneuvers. In all cases, participation in the study was voluntary, and refusal to participate in no way affected a pilot's rating or flight status. In fact, the pilots typically expressed interest in the study and pleasure at being asked to participate. None refused to participate.

A major advantage of incorporating the experiment into ongoing recurrent training in an airline simulator was the added realism that could be attained from the presence of completely operational aircraft systems at all crew member stations and from the use of flight procedures flown by pilots who were familiar with them and with the aircraft being simulated. It would have been difficult to obtain the same degree of realism in a flight research simulator since such simulators lack all but the most basic flight systems. The major disadvantage of conducting the study in the context of airline recurrent training was the set of restrictions imposed by the particular types of maneuvers that were part of the training syllabus. Since many of these maneuvers were different types of approaches, they lent themselves well to the purpose of the study.

Twenty crews composed of captain, first officer, and flight engineer 2 flew approaches of varying difficulty using PNF callouts for half their approaches and SYNCALL callouts for the other half of their approaches. Table 7 lists the different approaches in the order that they were flown. Approaches 1, 2, and 3 comprised "Set 1" and were always flown first. Approaches 4, 5, and 6 comprised "Set 2" and were always flown last. For a given crew, Approach Set 1 was flown with one of the callout systems (SYNCALL or PNF) and Approach Set 2 was flown with the opposite callout system. For Approach Set 1, both captains and first officers flew each of the three approaches (1, 2, and 3). For Approach Set 2, both captains and first officers flew the first two approaches (4 and 5), but only the captains flew the last approach (6), the single-engine approach and landing, in accordance with the airline procedures. Other than this discrepancy, the two approach sets were roughly balanced in that each began with a non-precision, manually flown approach. Next came an autopilot

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2. When scheduling did not permit the participation of a line flight engineer, a flight engineer instructor served as flight engineer to complete the three-man crew.

TABLE 7. APPROACHES FLOWN FOR SYNCALL EVALUATION

		PILOT FLYING APPROACH	
		CAPTAIN	FIRST OFFICER
SET 1	1	LOCALIZER BACK COURSE	LOCALIZER BACK COURSE
	2	DUAL LAND	ILS APPROACH ONLY
	3	2-ENGINE ILS	2-ENGINE ILS
SET 2	4	VOR RAW DATA	VOR RAW DATA
	5	SINGLE LAND	ILS APPROACH ONLY
	6	1-ENGINE LANDING	-------

assisted, precision approach. Finally there was an approach with one or more engines out. A given approach as flown by a captain or a first officer was flown to similar but not identical minimums due to the fact that captains are qualified to fly to lower minimums using more of the autopilot capability than are first officers. These small compromises in experimental design were deemed well worth the added realism that was gained by following airline procedures exactly. Table 8 shows the experimental design in block form.

For half the crews, the captain flew Approach Set 1 first, followed by the first officer flying Approach Set 1. Then the captain flew approaches 4 and 5 of Approach Set 2 followed by the first officer flying these two approaches. The last approach to be flown was always approach 6, by the captain. For the other half of the crews, the first officer flew first for each approach set followed by the captain. For half the crews assigned to each of these orders, the SYNCALL callouts were used for Approach Set 1 and the PNF callouts for Approach Set 2. For the other half of the crews, the PNF callouts were used for Approach Set 1 and the SYNCALL callouts for Approach Set 2. Appendix B contains detailed descriptions of the four resulting experimental orders for the approaches. 3

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3. Captain Walt Estridge and Instructor Pilot Colby Noyes were

TABLE 8. EXPERIMENTAL DESIGN

	APPROACH SET	
ORDER	SET 1	SET 2
1	SYNCALL CAPT F/O	PNF CAPT F/O
2	SYNCALL F/O CAPT	PNF F/O CAPT
3	PNF CAPT F/O	SYNCALL CAPT F/O
4	PNF F/O CAPT	SYNCALL F/O CAPT

DEVELOPMENT OF PERFORMANCE MEASURES

The man-vehicle system composed of three flight crew members interacting with one another and with the multiple systems of a modern jet transport aircraft is extremely complex; the task of measuring the effectiveness of different types of approach callout systems within that environment shares many of these complexities. Thus measurements of system effectiveness must take these system complexities into account. The measurements must also have operational relevance. They must relate directly to airline operations in a way that allows the system users (pilots, airline management, manufacturers, government regulatory agencies) to base decisions on system implementation directly on the data. Special flight performance measures were devised for this study. These measures were computed from the raw data on aircraft altitude, airspeed, selected approach speed, localizer deviation in degrees, and glideslope deviation in degrees. This raw data was sampled by the simulation computer once every 0.2 s and recorded once every 0.8 s during the experimental runs.

It was assumed that a pilot generally attempts to fly an aircraft within certain tolerances or windows and that as long as performance remains within the desired window, no correction will

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instrumental in evolving the formal experimental design into a workable flight training syllabus that conformed to the airline training requirements.

be deemed necessary by the pilot. This assumption is supported by the observation that both FAA and airline company regulations are written with allowable tolerances. Also, pilots if asked will say they fly to tolerances rather than try to keep a needle exactly centered or positioned. Indirect support is also suggested by the need to incorporate an "indifference threshold" into control models of human operator performance in order to obtain an acceptable fit between model-predicted performance and observed human operator performance (3). If this assumption is correct, measures of mean deviation from an ideal value for, say, airspeed would have little operational relevance to what a pilot judges to be good performance. For example, if the pilot attempts to fly within +/-5 KTS of a selected approach speed, he will be satisfied if he remains within +/-2 KTS but will make a correction if airspeed deviates by +9 KTS from approach speed. It would seem more relevant to keep track of whether a pilot flies inside or outside the tolerance window for a given parameter (airspeed, sink rate, localizer deviation, or glideslope deviation) and, when outside tolerance, to monitor the average and maximum deviations from the boundary of the tolerance window - not from the ideal value. This reasoning led to the choice of four computed operationally relevant measures of flight performance for the approach segment.

Percent Time out of Tolerance

For each of the three approach segments (I, II, and III) the percentage of the total duration of the segment that was flown outside the tolerance window for a given parameter was computed. This was done by taking the number of 0.8-s samples for which the parameter was outside the tolerance window and dividing by the number of 0.8-s samples in the entire segment.

Maximum Deviation

The maximum deviation, the deviation with the largest absolute value, and the direction of that deviation (positive, negative, right, left, etc.) for each of the four parameters for each of the three approach segments was recorded. This value was then corrected to reflect the deviation from the boundary of the tolerance window by subtracting the absolute value of the tolerance.

Mean Positive Deviation

Since deviations both right and left of the localizer, above and below glideslope, and faster or slower than approach speed could occur, mean deviations from the tolerance window boundary were computed for each direction. Due to the arbitrary assignment of signs (+ and -) to the direction of deviation by the simulation computer program, the term "positive" deviation is associated with real world directionality in an intuitively opposite manner. So, the arbitrary meanings of "positive" and "negative" are given for each of the four parameters below:

	"Positive" Deviation	"Negative" Deviation
Airspeed	IAS greater than V(APPR)	IAS less than V(APPR)
Sink Rate	Sink Rate greater than tolerance	Not applicable
Loc. Dev.	Deviation left of course	Deviation right of course
G/S Dev.	Deviation below G/S	Deviation above G/S

The mean positive deviation was computed by taking only those 0.8-s samples for which the parameter in question was out of tolerance in the "positive" direction, summing these deviations, and dividing by the number of out-of-tolerance samples. Thus, using an operational tolerance window of +/-8 KTS for IAS; if measured IAS was 158 KTS and selected V(APPR) was 141 KTS, then deviation from the positive tolerance window boundary of 149 KTS (141+8) is +9 KTS. For IAS samples of 158, 156, 150, 148, 149, 144, and 140 KTS, the mean positive deviation would be (9+7+1)/3 or +5.7 KTS. Expressed in terms of deviation from the selected approach speed, the mean positive deviation would be +13.7 KTS (5.7+8).

Mean Negative Deviation

Mean negative deviation from the tolerance window boundary for each flight parameter for each approach segment was computed for deviations in the "negative" direction as defined above. This was done in the same manner as the computation for "positive" deviations. However, this measure was not applicable for sink rate since there is no minimum acceptable sink rate for an approach. Tnus the computed "negative" deviations for sink rate were disregarded.

Flight Performance Parameters

As stated above, four parameters were measured for deviation outside allowable tolerance windows: airspeed, sink rate, localizer displacement, and glideslope displacement. These were chosen since they are the parameters which the pilot-not-flying and the flight engineer are required to monitor during the approach; and a comparison of performance on these four parameters as a function of callout system would give a measure of comparative effectiveness of the two callout systems in keeping the aircraft within allowable tolerance windows.

In choosing the operational tolerance window for each parameter, it was necessary to consider the discrepancies between the raw data in the Central Air Data Computer (CADC) (simulated by the simulation computer) and the visual indicators used by the pilots to determine current airspeed, sink rate, localizer deviation, and glideslope deviation. The pilots could not be expected to correct excessive airspeed as measured by the CADC, for example, if their airspeed indicators showed them to be within tolerance. Thus an operational tolerance for each flight parameter was derived by adding its operating manual ("book") tolerance (cf. Figure 3) and its "indicator" tolerance.

Operational Airspeed Tolerance

The operating manual for this air carrier calls for IAS to be within +/-5 KTS of selected approach speed (V(APPR)) once landing flaps have been extended. The permissible error between the digital autothrottle command setting, which controls the position of the orange bug on the airspeed indicator, and the actual position of the orange bug is +/-3 KTS. Thus the airspeed deviation as read by the pilot-not-flying and the flight engineer as they monitor airspeed from the airspeed indicator could appear as a 5 KT deviation when in fact it was an 8 KT deviation according to data in the CADC. Therefore, so as to count as out of tolerance only those airspeed deviations which appeared as deviations to the pilot-not-flying and the flight engineer, the book tolerance of 5 KTS and the indicator tolerance of 3 KTS were added together to produce an operational tolerance of +/-3 KTS. Figure 3 shows this pictorially.

Operational Sink Rate Tolerance

The book tolerance for sink rate varies with altitude above field (AFL). From 1000 feet AFL to 300 feet AFL, sink rate is not to exceed 1000 feet per minute (FPM). Below 300 feet AFL, it should not exceed 700 FPM. There is a considerable time lag, approximately 2 to 3 s, between instantaneous vertical speed and the indication of vertical speed shown on a vertical speed indicator (VSI). 4 Thus the pilots visual indication of sink rate is 2 to 3 s old. The recorded sink rate data was taken directly from the simulation computer and was thus a derived instantaneous vertical speed. So, an indicator tolerance was needed for this data that would compensate for the time lag. The computation of this tolerance involved the average standard deviation of a random sample of 2.4 s intervals of sink rate.

Sink rate was averaged over 40 sets of three consecutive

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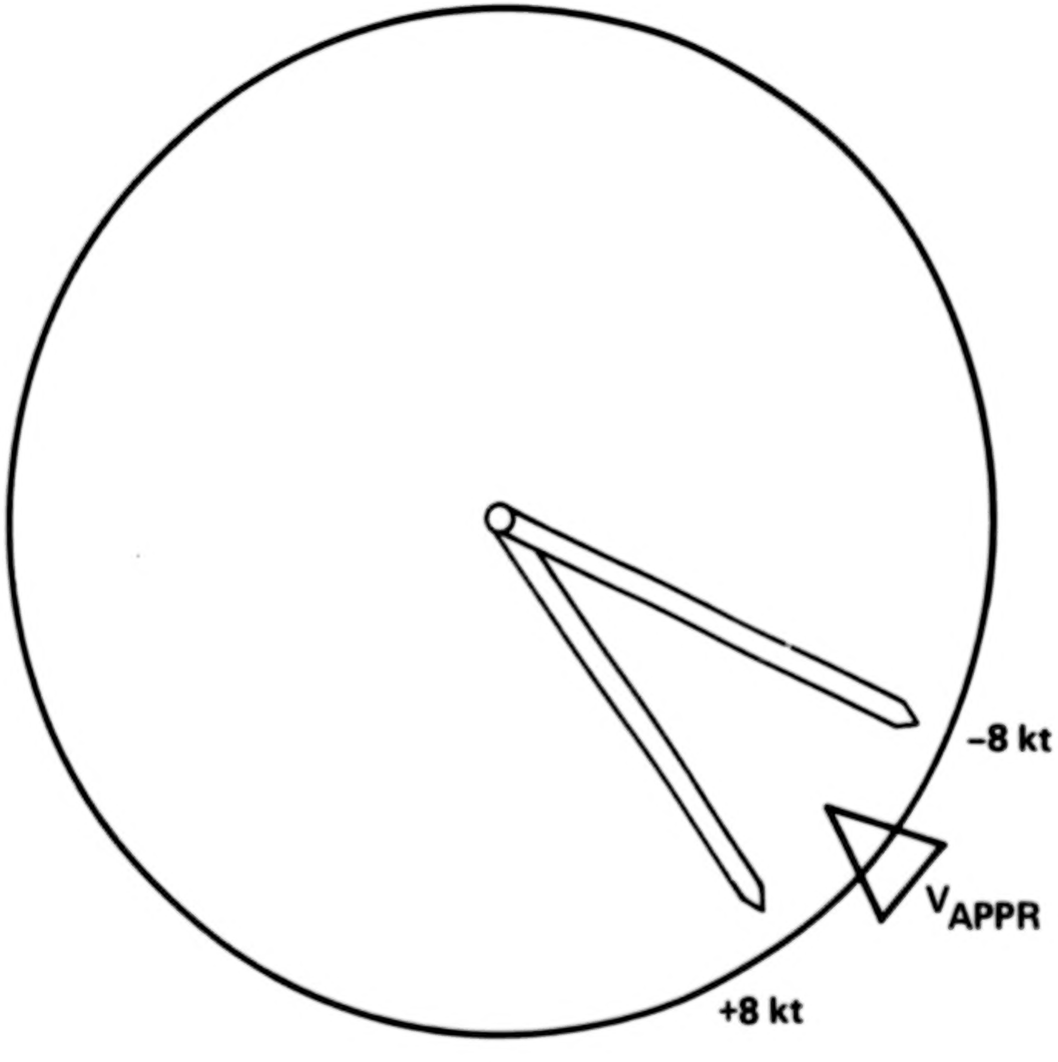
4. Although Instantaneous Vertical Speed Indicators (IVSI's) are installed in the wide-body jet used in this study, a 2 to 3 s time lag is designed into the indicators to to smooth the data going to the Central Air Data Computers (CADC's), which in turn drive the vertical speed instruments and altimeters in the cockpit. This is done to prevent momentary "opposite direction" vertical speed and altitude indications which would otherwise occur following changes in aircraft pitch. Pitch changes produce a momentary change in local pressure distribution at the static ports which results in a driving pressure opposite to that needed to give a true indication of direction of vertical speed.

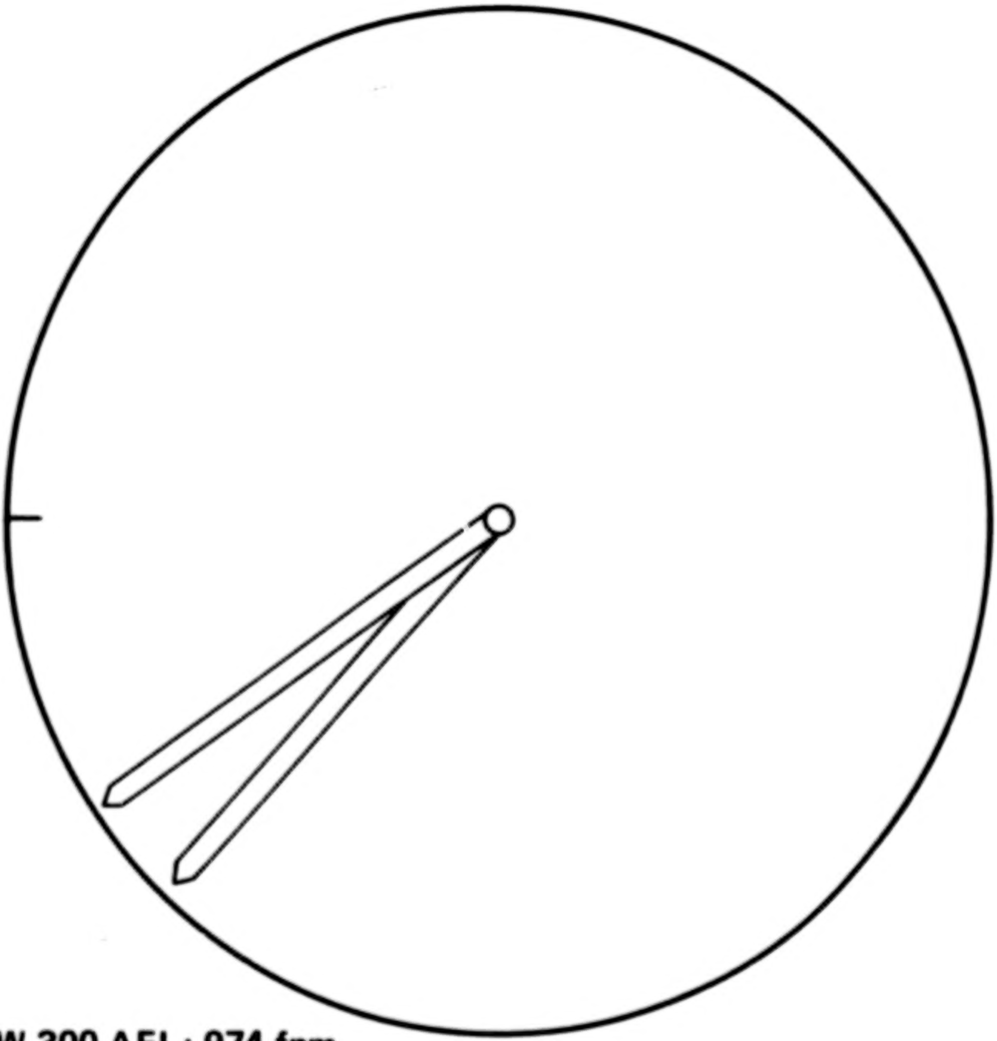
OPERATIONAL TOLERANCE: AIRSPEED



BOOK TOLERANCE	±5 kt
+ INDICATOR TOLERANCE	±3 kt
OPERATIONAL TOLERANCE	±8 kt

Figure 3. - Operational Tolerance: Airspeed.

OPERATIONAL TOLERANCE: SINK RATE



BELOW 300 AFL: 974 fpm

1000 TO 300 AFL: 1174 fpm

	1000 TO 300 AFL	BELOW 300 AFL
BOOK TOLERANCE	1000 fpm	700 fpm
+ INDICATOR TOLERANCE	174 fpm	174 fpm
OPERATIONAL TOLERANCE	1174 fpm	874 fpm

Figure 4. - Operational Tolerance: Sink Rate.

0.8-s samples of sink rate, i.e. over 2.4-s intervals. The standard deviation for each of these sets of three samples was computed. Then the mean and standard deviation of these 40 standard deviations was computed and these values added together. The original 40 sets of three 0.8-s samples of sink rate were taken from 10 of the 20 crews, randomly selected. For each of the ten crews selected, a 2.4-s interval of sink rate was taken for each of the four non-precision approaches (LOC BK CRS and VOR flown by Captain and by First Officer) flown by that crew. The altitude at which each 2.4 -s interval started was randomly chosen from the range 1 - 1000 feet AFL.

The mean and standard deviation of the 40 resulting standard deviations were 57 feet and 117 feet respectively. Their sum of 174 feet was used as the indicator tolerance for sink rate. Adding 174 feet to the book tolerances of 1000 FPM and 700 FPM resulted in operational tolerances of:

1000 - 300 AFL	1174 FPM
BELOW 300 AFL	874 FPM

Figure 4 shows this pictorially.

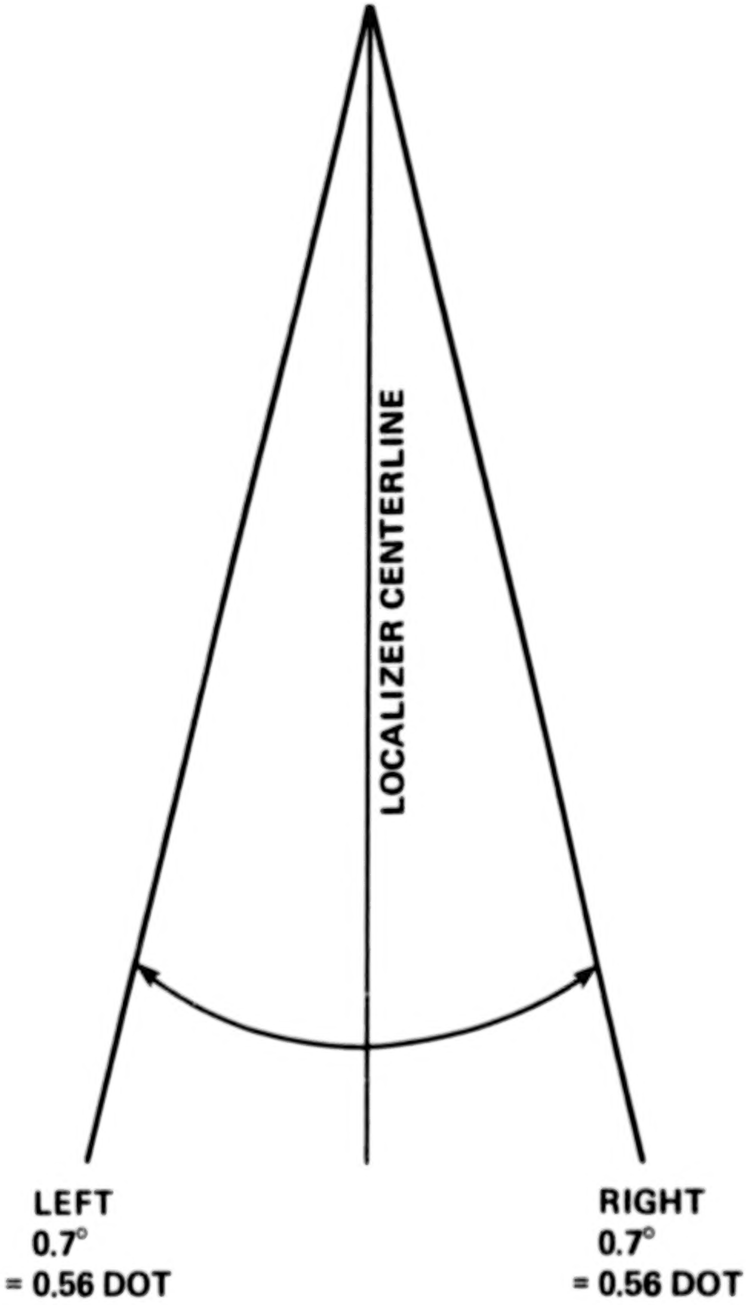
Operational Localizer Deviation Tolerance

The book tolerance for localizer deviations is +/-1/3 dot on the indicator scale, which is equal to +/-0.42 deg displacement from the center of the localizer course. The allowable tolerance for the localizer indicator needle is expressed in terms of "needlewidths". The needle referred to is the indicator needle which is driven right or left of center depending on whether the aircraft is left or right of the localizer course (valid only for the "front course" direction) The tolerance is +/-1 needlewidth. To convert needlewidth to dots - the unit used by the pilots - the needlewidth and the distance between center and full deflection to one side were measured on an actual Course Direction Indicator (CDI) which displays localizer and glideslope information. Accordingly, 1 needlewidth measured 0.22 dots or 0.28 deg. This indicator tolerance was added to the book tolerance of +/-1/3 dot (=+/-0.42 deg) to give an operational tolerance of +/-0.56 dots (=+/-0.70 deg). In round numbers, this operational tolerance is just slightly greater than +/-1/2 dot. See Figure 5.

Operational Tolerance for Glideslope Deviations

The indicator tolerance for glideslope deviation was computed in a manner analogous to that for localizer deviation. This resulted in the +/-1 needlewidth tolerance being equal to +/-0.18 dots (=+/-0.07 deg). The book tolerance of +/-1 dot (=+/-0.25 deg) plus the indicator tolerance gives an operational tolerance of +/-1.28 dots (=+/-0.32 deg), or approximately 1 1/4 dots. See Figure 6.

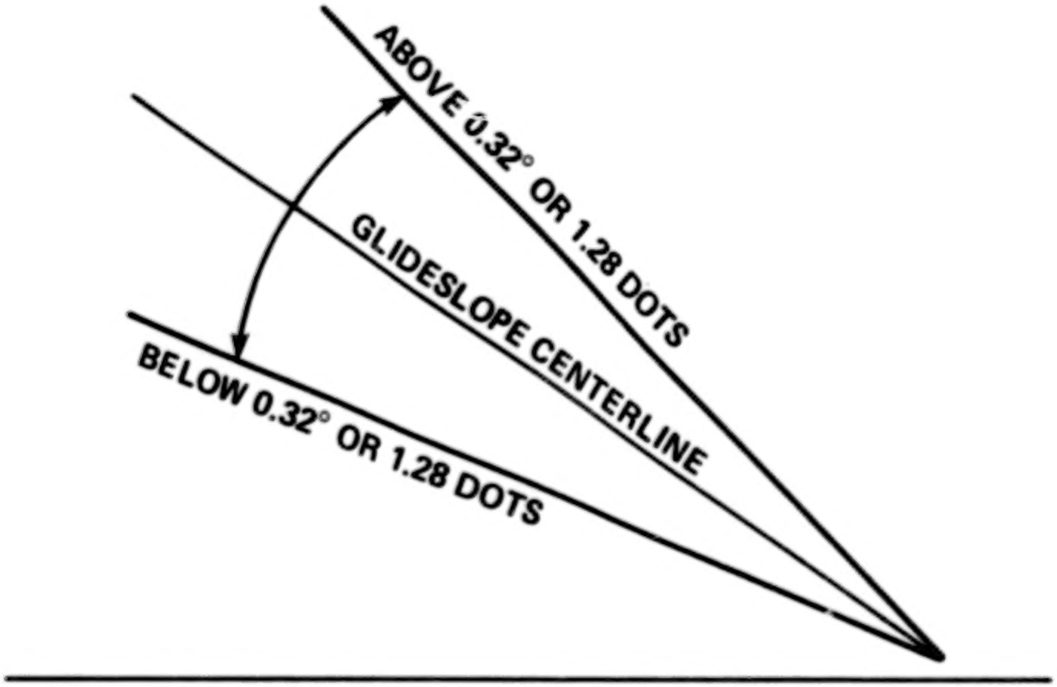
OPERATIONAL TOLERANCE: LOCALIZER


LOCALIZER CENTERLINE
LEFT
0.7°
= 0.56 DOT
RIGHT
0.7°
= 0.56 DOT

BOOK TOLERANCE	1/3 DOT
+ INDICATOR TOLERANCE	1 NEEDLEWIDTH
OPERATIONAL TOLERANCE	1/2+ DOT

Figure 5. - Operational Tolerance: Localizer.

OPERATIONAL TOLERANCE: GLIDESLOPE


ABOVE 0.32° OR 1.28 DOTS
GLIDESLOPE CENTERLINE
BELOW 0.32° OR 1.28 DOTS

BOOK TOLERANCE	1 DOT
+ INDICATOR TOLERANCE	1 NEEDLEWIDTH
OPERATIONAL TOLERANCE	1¼ DOTS

Figure 5. - Operational Tolerance: Glideslope.

MEASURES OF PILOT JUDGMENTS OF SYSTEM PERFORMANCE

The purpose of administering a formal post-experiment debriefing to the pilots was to obtain in a systematic and objective fashion the pilots' subjective responses to the two callout systems. It was expected that experienced line pilots would be able to answer questions about potential advantages and disadvantages of the two systems that could not be otherwise measured by flight performance parameters. By presenting each pilot with an identical set of questions and by designing the questions so that possible answers were mutually exclusive and yet covered the entire range of possible answers by the inclusion of an option for an "other" response, it was possible to collect data that could be submitted to non-parametric statistical tests for significance.

Design of Pilot De-Briefing Materials

A copy of the de-briefing form exactly as presented to the pilots is in Appendix C. Preference grids, a measure that had been successfully used with airline pilots in a study of line pilot preferences for design of cockpit warning systems (4) were used to study the effects of type of approach conditions (Night VFR, Day VFR, IFR to Weather Minimums, or Abnormal/Emergency) on whether or not pilots would want a particular callout to be made by the Pilot-not-Flying and/or by SYNCALL. A 7-point scale from "unsafe" to "highly desirable" with "no preference" in the middle was used to compare the present PNF system, the SYNCALL system as configured for the study, the PNF system as reconfigured according to the pilot's own responses on the preference grid concerning desirable callouts, and the SYNCALL system as reconfigured according to the pilot's own preference grid responses. Pilots were asked to rate the intelligibility of four types of speech they had heard in the simulator on a scale of 0% to 100%. The four types of speech were 1) SYNCALL synthesized speech, 2) Terminal Radar Control (TRACON) ATC human voice messages, 3) Tower ATC human voice messages, and 4) Pilot-not Flying human voice messages (callouts and other crew voice communications). The last item was a list of possible modifications to the SYNCALL system as configured for the study. Pilots were asked to rate each modification on a scale of 1) Highly Desirable, 2) Desirable, 3) No preference, 4) Undesirable, or 5) Unsafe. At the end of the list were blank lines with instructions to fill in additional modifications the pilots thought they would want. They were asked to rate their own suggested modifications using the same 5-point scale. This concluded the main debriefing form.

A second, optional form was used to obtain additional, more detailed information about the individual callouts from those pilots who were interested enough and willing to spend additional time. This form consisted of a set of semantic differential scales (5) chosen for their relevance to cockpit flight information systems. Several of these scales had been previously used in the study on line pilot preferences for cockpit warning system design (4) with consistent results. Others were added specifically for this study. Table 9 lists the semantic differential scales and Table 10 lists the set of callouts by each system that were measured with these scales. For purposes of comparison, the current GPWS "Whoop, Whoop. Pull up!" and "Glideslope" voice messages were included in the set of callouts to be rated on each of the semantic differential scales. These items were included because they were then and still are the only examples of electronically generated speech that have been experienced by all airline pilots. Both the de-briefing form and the optional semantic differential form were designed to be self-administered. Finally, to preserve annonymity, no names or other personal information were requested on either form.

TABLE 9. SEMANTIC DIFFERENTIAL SCALES

GOOD..............................BAD
WORTHLESS....................VALUABLE
LOUD.............................SOFT
ACTIVE.........................PASSIVE
NOISY...........................QUIET
SAFE.......................DANGEROUS
ALERTING...............IMPERCEPTIBLE
ANNOYING....................SOOTHING
HELPFUL..................DETRIMENTAL
DEPENDABLE................UNRELIABLE
DISRUPTIVE..............COORDINATING

TABLE 10. TYPES OF CALLOUTS MEASURED WITH SEMANTIC DIFFERENTIAL

AS SPOKEN BY PILOT-NOT-FLYING AND BY SYNCALL

1000-FOOT CALLOUT
TEN-FOOT CALLOUTS
HUNDRED FOOT CALLOUTS
G/S & LOCALIZER INTERCEPT
FINAL APPROACH FIX & CROSSING ALTITUDE
AIRSPEED DEVIATIONS
SINK RATE DEVIATIONS
G/S & LOCALIZER DEVIATIONS
DECISION HEIGHT, MDA, & 100 ABOVE MDA

AS SPOKEN BY GPWS

"WHOOP WHOOP PULL UP"
"GLIDESLOPE"

PROCEDURE

Each crew received a taped briefing of approximately 5-minutes length explaining the scope and purpose of the experiment. If all crew members decided to participate, they were given a taped description of the SYNCALL system compared to the PNF system accompanied by diagrams on projected transparencies. General questions about systems operation were encouraged. Next, the pilots heard a taped introductory passage by the speech synthesizer to familiarize them with the electronic voice quality and "accent" of the speech. This was followed by a recording of each type of approach callout in the SYNCALL system with each callout pronounced twice. To speed learning of the synthesizer accent, the printed text of the speech was displayed concurrently. Tables 11 (following) and 6 (in section on Voice Message Design) are a reproduction of the printed displays.

After the 15-minute briefing, the instructor pilot conducted the normal pre-simulation briefing on the flight maneuvers to be practiced. This was followed by four hours of recurrent simulator training in accordance with the appropriate set of experimental conditions for each crew. The first hour was spent on other maneuvers and served as a "warm-up" period before flying the experimental approaches. A break of 15 minutes was scheduled between Approach Set 1 and Approach Set 2 in accordance with the normal training breaks used. To simulate the potential mutual

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TABLE 11. INTRODUCTORY PASSAGE BY SPEECH SYNTHESIZER PRESENTED TO PILOTS FOR FAMILARIZATION WITH SYNCALL VOICE

> YOU ARE ABOUT TO HEAR THE SYNCALL SYSTEM SAY EACH OF THE APPROACH CALLOUTS SO YOU CAN GET FAMILIAR WITH THE SOUND OF THE VOICE AND WITH EACH OF THE CALLOUTS. THE CALLOUTS ARE LISTED IN ORDER ON THE SLIDE SO YOU CAN LOOK AT THEM AS YOU HEAR THEM. EACH CALLOUT WILL BE SAID TWO TIMES WITH A SLIGHT PAUSE BETWEEN REPETITIONS.

---

masking of concurrent speech messages from Air Traffic Control (ATC) and the SYNCALL callouts, a pre-recorded set of Approach and Tower transmissions, addressed to other aircraft, were played over the cockpit headsets to the pilots. The pilot instructor issued clearances in ATC phraseology to the crew, and they read back their clearances with the cockpit microphone as they would have done in the actual aircraft. The author controlled other aircraft ATC message presentation on different simulated ATC frequencies to assure that the simulated ATC chatter was appropriate for the runway in use and the simulator's position in the airspace. The ATC tapes were edited from actual ATC communications recorded at the airport that was simulated for the study.

Flight performance data was collected for each approach by the simulation computer. Data collection began at 3000 feet AFL and continued until either the initiation of a go-around on a missed approach or the touchdown on a landing. The following flight parameters were sampled once every 0.8 s:

1) Indicated Airspeed (IAS)
2) Selected Approach Speed (from ATS command airspeed)
3) Altitude Mean Sea Level (MSL)
4) Glideslope deviation
5) Localizer deviation
6) Vertical Speed
7) Elapsed Time

The times of occurrence of each callout together with actual values that triggered any deviation callouts were also recorded. The cockpit audio including crew conversation, ATC, approach callouts, and cockpit noise was recorded on audio tape.

After the simulator session, each pilot completed the debriefing form and discussed the experiment with the author. Those pilots who were interested also completed the optional semantic differential form. Many took it with them and mailed the completed form back. Pilots were offered a copy of the final report, when published.

RESULTS

The results will be presented in sections according to the individual measures (flight performance, system reliability, system interference with other systems) that were used to assess callout system effectiveness. Because of the large number of different measures used, there will be some discussion of each of the major types of results in the respective results sections. Then the results of the separate measures will be compared for consistency. Finally, a general discussion will treat the results from different measures as a whole.

Flight Performance Results

Analysis of Variance (AOV) was used to test for statistically significant effects of 1) type of callout system, 2) pilot flying, 3) order of pilot flying, and 4) type of approach. Analysis of variance was chosen as a means of testing the data to determine the probability that any observed differences in the data associated with each of the four effects above could be due to chance rather than be caused by those effects themselves. Airspeed, sink rate, localizer deviations, and glideslope deviations were analyzed as appropriate to each approach type for each of the four measures: (1) percent time out of tolerance, (2) maximum deviation beyond tolerance, (3) maximum "positive" deviation, and (4) maximum "negative" deviation.

First, all five approaches (1-engine approach & landing not included here) were compared for the flight parameters they had in common, namely airspeed and sink rate, for each of the four measures listed above. The final approach was divided into four segments for analysis, with the assumption that these segments might be flown differently and that the operational tolerances for the different segments would be different. The four segments were:

I: Final Approach Fix (FAF) to 1000 AFL
II: 1000 AFL to 500 AFL
III: 500 AFL to DH or MDA (depending on type approach)
IV: DH or MDA to Landing or Go-around
(depending on how approach was terminated)

Due to large differences among the five types of approach in Segment I, the AOV's were performed only on the data for Segments II, III, and IV. While a few callouts were made by SYNCALL or the Pilot-not-Flying (PNF) during Segment I (outer marker with AFL crossing altitude, localizer deviations, and glideslope deviations), most of the callouts occur from 1000 AFL on down. Thus any differences in performance due to the type of callout system would be expected to occur in segments II, III, and IV.

Figures 7 and 8 show the different 4-way AOV's that were performed. The comparison of all five approaches was done with a 2x2x2x3 mixed design for approaches 1, 2, and 3 and with a 2x2x2x2 mixed design for approaches 4 and 5. The reason for the division of the analysis into two parts: Approaches 1, 2, and 3 versus Approaches 4 and 5 was that those pilots who flew one set of approaches with one callout system flew the other set of approaches with the other callout system. Analysis of all five approaches in a 2x2x2x5 mixed design would have resulted in an unbalanced design. There were thus 24 four-way AOV's (3 segments x 4 measures x 2 parameters) for approaches 1, 2, and 3 and another 24 four-way AOV's for approaches 4 and 5.

Analyses of All Approaches Overall

Approach Segment II: 1000 AFL to 500 AFL

Between 1000 and 500 feet AFL the only factor with significant effects on airspeed and sink rate performance was type of approach. Significant differences ($p<0.001$) were obtained for sink rate performance for both sets of approaches (1,2,3) and (4,5) for the following measures:

Percent time out of tolerance
(Operating tolerance = -1174 FPM)

Maximum deviation beyond tolerance
Mean "positive" deviation beyond operating tolerance

Significant differences ($p<0.001$) were obtained for airspeed performance only for the first set of approaches (1,2,3). The following measures resulted in significant differences:

Percent time out of tolerance (Oper Tol = +/-8 KTS)
Maximum deviation from Approach Speed
Mean "positive" deviation from Approach Speed

The term "mean negative deviation" as applied to the data for sink rate and airspeed deserves some comment. During approach and landing, only sink rates greater than tolerance are of concern. "Negative deviation", i.e. rate of climb, has no upper limit and was therefore not analyzed.

For airspeed, there were no instances for any of the 20 crews for either pilot for any of the approaches for which airspeed was below the minimum operating tolerance of -8 KTS. Since all data points were thus equal to 0, analysis of variance was neither appropriate nor necessary.

Since the results for mean "positive" deviation were analogous to those for percent time out of tolerance and for maximum deviation, Table 12 presents means (N=40 pilots) just for percent time out of tolerance and means for maximum sink rate deviation and Table 13 presents similar data for airspeed for Segment II.

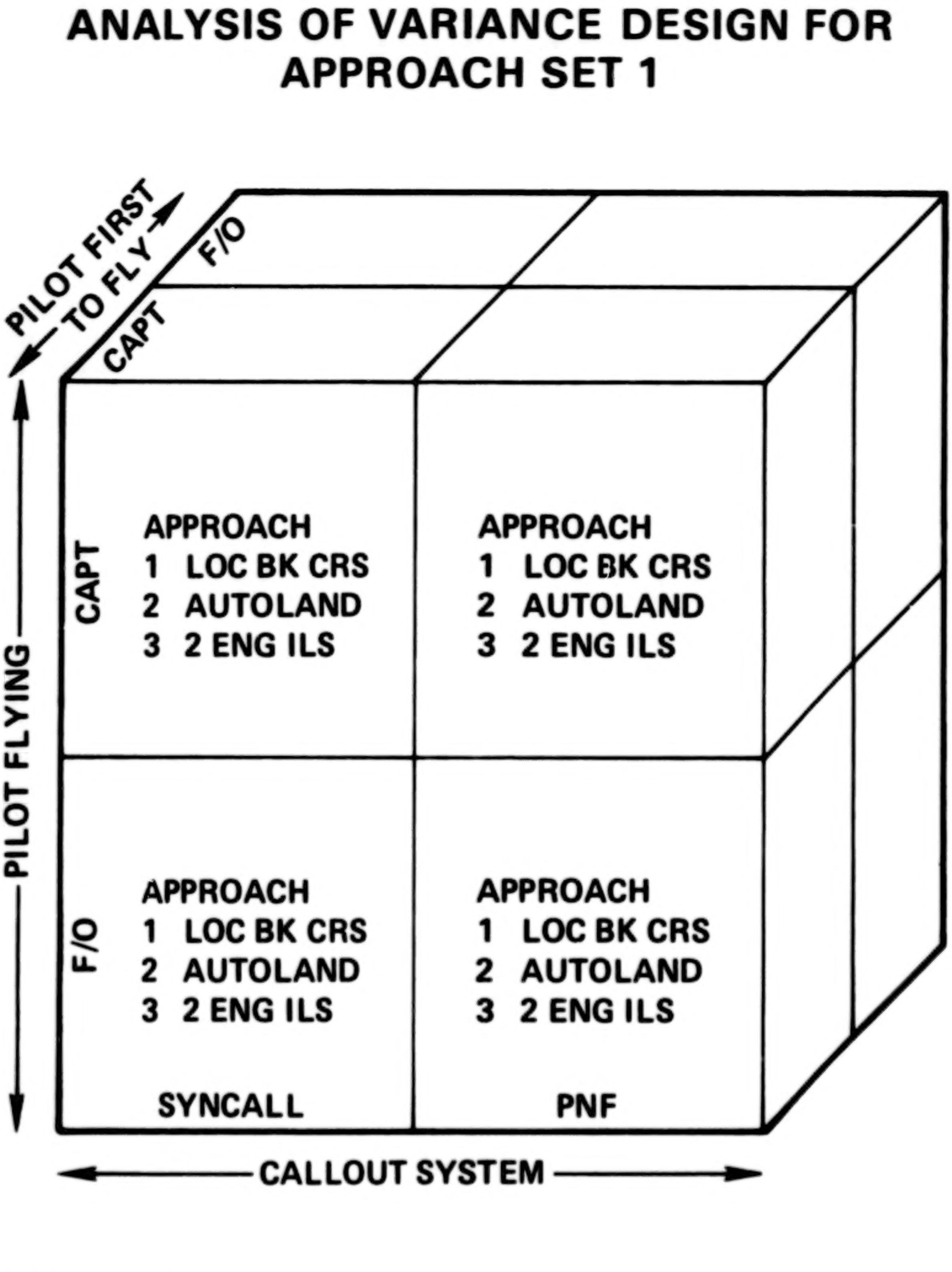
ANALYSIS OF VARIANCE DESIGN FOR APPROACH SET 1
PILOT FIRST TO FLY
F/O
CAPT
PILOT FLYING
CAPT
F/O
APPROACH
1 LOC BK CRS
2 AUTOLAND
3 2 ENG ILS
APPROACH
1 LOC BK CRS
2 AUTOLAND
3 2 ENG ILS
APPROACH
1 LOC BK CRS
2 AUTOLAND
3 2 ENG ILS
APPROACH
1 LOC BK CRS
2 AUTOLAND
3 2 ENG ILS
SYNCALL
PNF
CALLOUT SYSTEM

Figure 7. - Analysis of Variance Design for Approach Set I.

ANALYSIS OF VARIANCE DESIGN FOR APPROACH SET 2

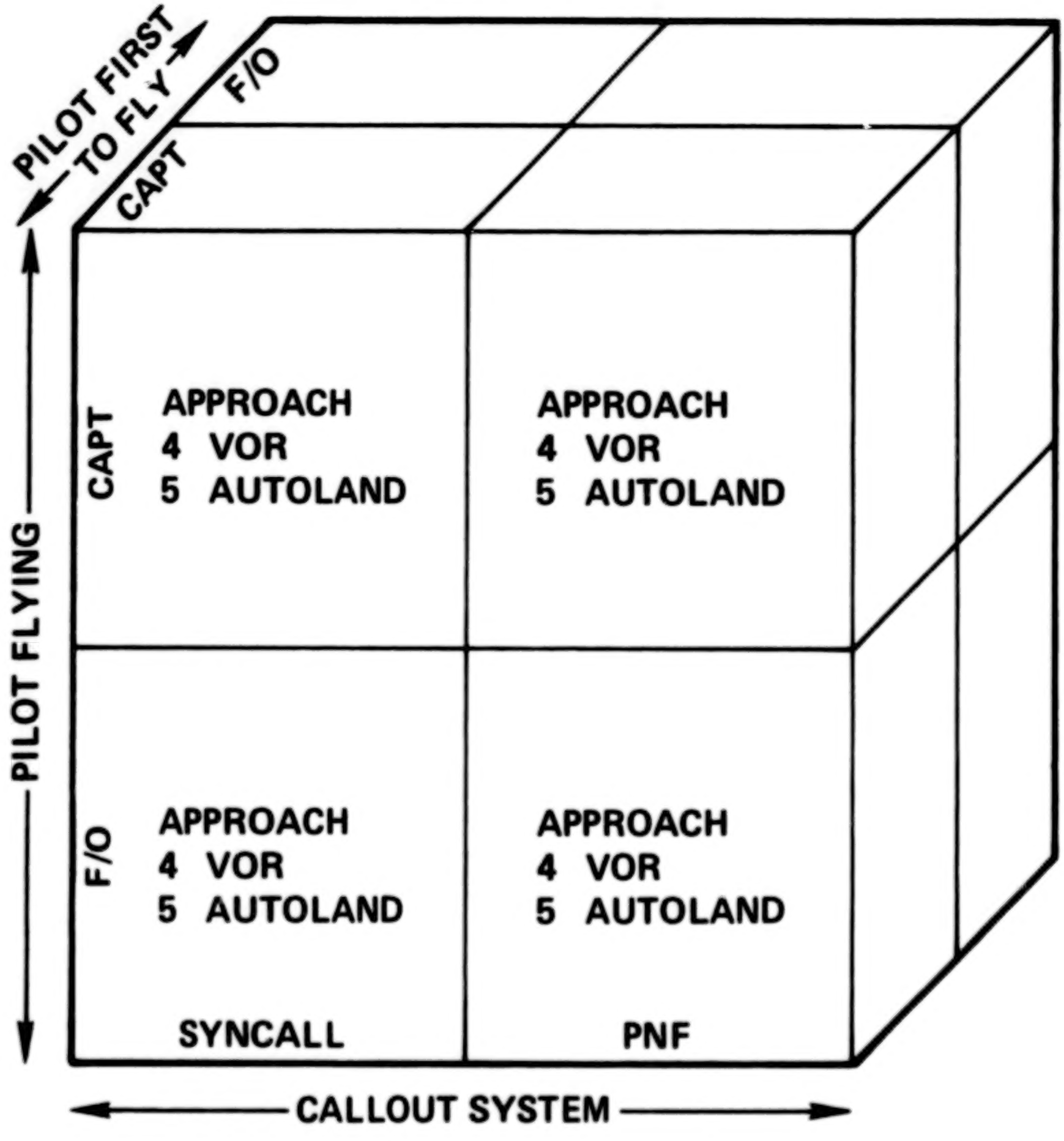
PILOT FIRST TO FLY
F/O
CAPT
PILOT FLYING
CAPT
F/O
APPROACH
4 VOR
5 AUTOLAND
APPROACH
4 VOR
5 AUTOLAND
APPROACH
4 VOR
5 AUTOLAND
APPROACH
4 VOR
5 AUTOLAND
SYNCALL
PNF
CALLOUT SYSTEM

Figure 3. - Analysis of Variance Design for Approach Set II.

TABLE 12. SINK RATE PERFORMANCE FOR ALL APPROACHES DURING SEGMENT II: 1000 FT AFL TO 500 FT AFL

TYPE APPROACH	N = 40 PILOTS MEAN PERCENT TIME OUT OF TOLERANCE	MEAN MAXIMUM DEVIATION
1 LOCALIZER BACK COURSE	39 %	1483 FPM
2 DUAL LAND / ILS APPR ONLY	1 %	1131 FPM
3 2-ENGINE ILS	1 %	1173 FPM
4 VOR RAW DATA	30 %	1405 FPM
5 SINGL LAND / ILS APPR ONLY	1 %	1174 FPM

Note: The were no statistically significant differences due to Pilot Flying, Order, or Type of Callout System During Segment II

TABLE 13. AIRSPEED PERFORMANCE FOR ALL APPROACHES DURING SEGMENT II: 1000 FT AFL TO 500 FT AFL

TYPE APPROACH	N = 40 PILOTS MEAN PERCENT TIME OUT OF TOLERANCE	MEAN MAXIMUM DEVIATION
1 LOCALIZER BACK COURSE	34 %	+ 8 KTS
2 DUAL LAND / ILS APPR ONLY	44 %	+ 8 KTS
3 2-ENGINE ILS	16 %	+ 5 KTS
4 VOR RAW DATA	41 %	+ 10 KTS
5 SINGL LAND / ILS APPR ONLY	39 %	+ 12 KTS

Note: There were no statistically significant differences for Pilot Flying, Order, or Type of Callout System during Segment II

It is not surprising that sink rate performance on autopilot-assisted ILS and Category II Autoland approaches was better than for the manually flown non-precision approaches. It is however surprising to note that airspeed performance between 1000 and 500 feet AFL was worse for the Autoland approaches than for the manually flown approaches. Possibly the pilot anticipates needs for slight adjustments in pitch and power as the landing flaps and gear extend and is in this way able to track desired approach speed better than the autothrottle system which can only react after airspeed deviates from programmed tolerances. No factors other than type of approach were significant for Segment II.

Approach Segment III: 500 AFL to DH or MDA

Between 500 feet AFL and DH or MDA (depending on type of approach) there were significant effects for type of approach ($p<0.001$), callout system ($p<0.05$), and pilot flying ($p<0.05$). Table 14 (a-d) shows means (N=40 pilots) for the sink rate and airspeed data for Segment III. The only significant effect of callout system was for maximum sink rate deviation for approaches 4 and 5 with SYNCALL approaches resulting in no instances of sink rate exceeding the maximum operating tolerance of -1174 fpm and the PNF callout system resulting in a mean maximum deviation of 27 FPM beyond the operating tolerance of -1174 fpm. No significant differences in sink rate due to callout system occurred for Approaches 1, 2, and 3. Pilot flying had a significant effect ($p<0.05$) on percent time out of tolerance (+/-3 KTS) for airspeed for approaches 1, 2, and 3. Captains on the average were out of tolerance on airspeed 22% of the time while First Officers were out of tolerance only 10% of the time. As with data for the previous segment, the type of approach flown had a significant effect ($p<0.001$) on both airspeed and sink rate. In this segment, between 500 AFL and DH or MDA, performance was better for the autopilot-assisted ILS approaches than for the manually flown non-precision approaches.

TABLE 14a. AIRSPEED PERFORMANCE FOR SET 1 APPROACHES DURING SEGMENT III: 500 FT AFL TO DH OR MDA

FACTOR		N = 40 PILOTS MEAN PERCENT TIME OUT OF TOLERANCE	MEAN MAXIMUM DEVIATION
CALLOUT SYSTEM	SYNCALL	13 %	+ 3 KTS
	PNF	20 %	+ 4 KTS
PILOT WHO FLEW FIRST	CAPTAIN	15 %	+ 3 KTS
	FIRST OFFICER	18 %	+ 4 KTS
PILOT FLYING	CAPTAIN	22 %	+ 4 KTS
	FIRST OFFICER	10 %	+ 3 KTS
APPROACH TYPE	1 LOCALIZER BACK COURSE	34 %	+ 6 KTS
	2 DUAL LAND/ILS APPR ONLY	3 %	+ 1 KT
	3 2-ENGINE ILS	13 %	+ 3 KTS

TABLE 14b. AIRSPEED PERFORMANCE FOR SET 2 APPROACHES DURING SEGMENT III: 500 FEET AFL TO DH OR MDA

FACTOR		N = 40 PILOTS MEAN PERCENT TIME OUT OF TOLERANCE	MEAN MAXIMUM DEVIATION
CALLOUT SYSTEM	SYNCALL	20 %	+ 3 KTS
	PNF	12 %	+ 3 KTS
PILOT WHO FLEW FIRST	CAPTAIN	19 %	+ 3 KTS
	FIRST OFFICER	14 %	+ 3 KTS
PILOT FLYING	CAPTAIN	13 %	+ 2 KTS
	FIRST OFFICER	19 %	+ 5 KTS
APPROACH TYPE	4 VOR RAW DATA	31 %	+ 5 KTS
	5 SINGL LAND/ILS APPR ONLY	2 %	+ 2 KTS

TABLE 14c. SINK RATE PERFORMANCE FOR SET 1 APPROACHES DURING SEGMENT III: 500 FEET AFL TO DH OR MDA

FACTOR		N = 40 PILOTS MEAN PERCENT TIME OUT OF TOLERANCE	MEAN MAXIMUM DEVIATION
CALLOUT SYSTEM	SYNCALL	6 %	56 FPM
	PNF	6 %	51 FPM
PILOT WHO FLEW FIRST	CAPTAIN	5 %	44 FPM
	FIRST OFFICER	7 %	63 FPM
PILOT FLYING	CAPTAIN	7 %	70 FPM
	FIRST OFFICER	5 %	37 FPM
APPROACH TYPE	1 LOCALIZER BACK COURSE	11 %	106 FPM
	2 DUAL LAND/ILS APPR ONLY	0 %	0 FPM
	3 2-ENGINE ILS	6 %	58 FPM

TABLE 14d. SINK RATE PERFORMANCE FOR SET 2 APPROACHES DURING SEGMENT III: 500 FEET AFL TO DH OR MDA

FACTOR		N = 40 PILOTS MEAN PERCENT TIME OUT OF TOLERANCE	MEAN MAXIMUM DEVIATION
CALLOUT SYSTEM	SYNCALL	0 %	0 FPM
	PNF	6 %	27 FPM
PILOT WHO FLEW FIRST	CAPTAIN	6 %	14 FPM
	FIRST OFFICER	1 %	13 FPM
PILOT FLYING	CAPTAIN	3 %	16 FPM
	FIRST OFFICER	4 %	11 FPM
APPROACH TYPE	4 VOR RAW DATA	6 %	23 FPM
	5 SINGL LAND/ILS APPR ONLY	1 %	3 FPM

Note: For sink rate, Maximum Deviation refers to the deviation BEYOND the operation tolerance of 1174 fpm.

Approach Segment IV: DH or MDA to Landing or Go-Around

Between DH or MDA and Landing or Go-Around, there were also significant effects for type of approach ($p<0.05$) and callout system ($p<0.05$). Table 15 (a-d) shows the means ($N=40$ pilots) for the sink rate and airspeed performance data for Segment IV. In this segment, the only significant difference resulting from type of callout system was for percent time out of tolerance for airspeed, and the difference was in the opposite direction from that which was expected - performance was worse with SYNCALL (35% time out of tolerance) than with PNF callouts (21% time out of tolerance). This reversal occurred only for the second set of approaches (Numbers 4 and 5). One possible explanation is that the crews who were using PNF callouts for these approaches had already experienced SYNCALL for the first set of approaches and may have experienced some learning transfer to fly tighter tolerances with SYNCALL which carried over into their performance without SYNCALL in the second set of approaches. Further examination of the raw data would be needed to determine whether such transfer effects may have actually occurred. It should be noted that airspeed performance was generally worse for the second set of approaches than for the first, possibly due to fatigue. All experimental runs were flown between 20:00 and 24:00 Central Time, causing the second set of approaches to be flown between 22:30 and 24:00.

TABLE 15a. AIRSPEED PERFORMANCE FOR SET 1 APPROACHES DURING SEGMENT IV: DH OR MDA TO LANDING OR GO-AROUND

FACTOR		N = 40 PILOTS MEAN PERCENT TIME OUT OF TOLERANCE	MEAN MAXIMUM DEVIATION
CALLOUT SYSTEM	SYNCALL	13 %	+ 4 KTS
	PNF	21 %	+ 4 KTS
PILOT WHO FLEW FIRST	CAPTAIN	16 %	+ 4 KTS
	FIRST OFFICER	11 %	+ 3 KTS
APPROACH TYPE	1 LOCALIZEWR BACK COURSE	23 %	+ 4 KTS
	2 DUAL LAND/ILS APPR ONLY	4 %	+ 2 KTS
	3 2-ENGINE ILS	25 %	+ 6 KTS

TABLE 15b. AIRSPEED PERFORMANCE FOR SET 2 APPROACHES DURING SEGMENT IV: DH OR MDA TO LANDING OR GO-AROUND

FACTOR		N = 40 PILOTS MEAN PERCENT TIME OUT OF TOLERANCE	MEAN MAXIMUM DEVIATION
CALLOUT SYSTEM	SYNCALL	35 %	+ 14 KTS
	PNF	21 %	+ 11 KTS
PILOT WHO FLEW FIRST	CAPTAIN	25 %	+ 11 KTS
	FIRST OFFICER	25 %	+ 13 KTS
APPROACH TYPE	4 VOR RAW DATA	23 %	+ 9 KTS
	5 SINGL LAND/ILS APPR ONLY	36 %	+ 16 KTS

Summary of 4-way AOV's

While there were statistically significant differences for type of callout system, the absolute magnitude of the differences was generally small. This is especially true for the sink rate data. Also, the differences due to type of approach were of far greater magnitude than those due to either the type of callout system or the pilot flying. Order of pilot flying had no significant effects on sink rate or airspeed performance.

TABLE 15c. SINK RATE PERFORMANCE FOR SET 1 APPROACHES DURING SEGMENT IV: DH OR MDA TO LANDING OR GO-AROUND

FACTOR		N = 40 PILOTS	
		MEAN PERCENT TIME OUT OF TOLERANCE	MEAN MAXIMUM DEVIATION
CALLOUT SYSTEM	SYNCALL	8 %	50 FPM
	PNF	3 %	59 FPM
PILOT WHO FLEW FIRST	CAPTAIN	3 %	65 FPM
	FIRST OFFICER	8 %	79 FPM
APPROACH TYPE	1 LOCALIZER BACK COURSE	13 %	118 FPM
	2 DUAL LAND/ILS APPR ONLY	2 %	16 FPM
	3 2-ENGINE ILS	10 %	53 FPM

TABLE 15d. SINK RATE PERFORMANCE FOR SET 2 APPROACHES DURING SEGMENT IV: DH OR MDA TO LANDING OR GO-AROUND

FACTOR		N = 40 PILOTS	
		MEAN PERCENT TIME OUT OF TOLERANCE	MEAN MAXIMUM DEVIATION
CALLOUT SYSTEM	SYNCALL	5 %	129 FPM
	PNF	9 %	65 FPM
PILOT WHO FLEW FIRST	CAPTAIN	6 %	112 FPM
	FIRST OFFICER	9 %	117 FPM
APPROACH TYPE	4 VOR RAW DATA	9 %	166 FPM
	5 SINGL LAND/ILS APPR ONLY	2 %	2 FPM

Analyses of Individual Approaches

Because of the large differences in performance as a function of type of approach and because the major purpose of the study was to measure manual flight performance, further AOV's were performed on individual approaches. The approaches chosen for this further analysis were the non-precision approaches, the 2-Engine ILS, and (for Captains only) the 1-Engine Landing.

Figure 9 shows the different AOV's that were performed on the individual approaches. The design for analysis of individual approaches was a 2x2x2 across subjects AOV.

All together this resulted in 3 segments x 4 measures x 4 parameters for each of the 3 precision approaches plus 3 segments x 4 measures x 3 parameters for the Localizer Back Course approach plus 3 segments x 4 measures x 2 parameters for the VOR approach for a total of 204 3-way AOV's.

When individual approaches were analyzed, Type of Callout System (SYNCALL or PNF) was the only factor that had statistically significant effects on flight performance. Furthermore, significant differences in flight performance resulted only for the non-precision approaches (Localizer Back Course and VOR) only in the lower altitude segments (III: 500 AFL to MDA; and IV: MDA to Landing/Go-Around) and only for airspeed and sink rate performance - not course tracking performance (Localizer and Glideslope where applicable). In each case, flight performance was better with SYNCALL than with PNF callouts.

Airspeed Deviations During Localizer Back Course Approach

Table 16 shows airspeed performance for Segment IV (MDA to Landing/Go-Around) for the Localizer Back Course Approach for each callout system. There were 19 such approaches flown by either a Captain or a First Officer for which SYNCALL was used and 17 approaches for which PNF callouts were used. [5] Percent time out of tolerance for the SYNCALL approaches was 13% compared to 34% time out of tolerance for the PNF approaches. This difference was significant ($F=4.30$, $df=1,28$, $p<0.05$) Similarly, fewer approaches were flown out of tolerance at all (5) with SYNCALL compared to PNF (12).

To discover in more detail what was occurring with airspeed performance during these approaches, a tally was taken to obtain the number of approaches that were in tolerance and outside tolerance at an earlier point in the approach (500 feet) when the normal 500 foot callout with airspeed and sink rate is made and again at the beginning of the segment for which performance differences occurred (MDA). Tables 17 a and b show number of approaches in and out of tolerance for SYNCALL and PNF callouts at 500 AFL and the corresponding data taken at MDA. A Chi-Square analysis resulted in no significant correlation between callout system and airspeed performance at 500 AFL ($X(2)=0.07$, $df=1$, $p>0.10$). But the Chi-Square for the data at MDA was significant ($X(2)=5.56$, $df=1$, $p<0.02$). Thus, while there was no difference

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[5] If the crew on a given approach initiated a go-around before reaching MDA (as sometimes happened) then there was no data collected for that approach for that crew. This is the reason for the unequal N number of approaches for the two callout systems.

DESIGN FOR ANALYSIS OF VARIANCE FOR INDIVIDUAL APPROACHES

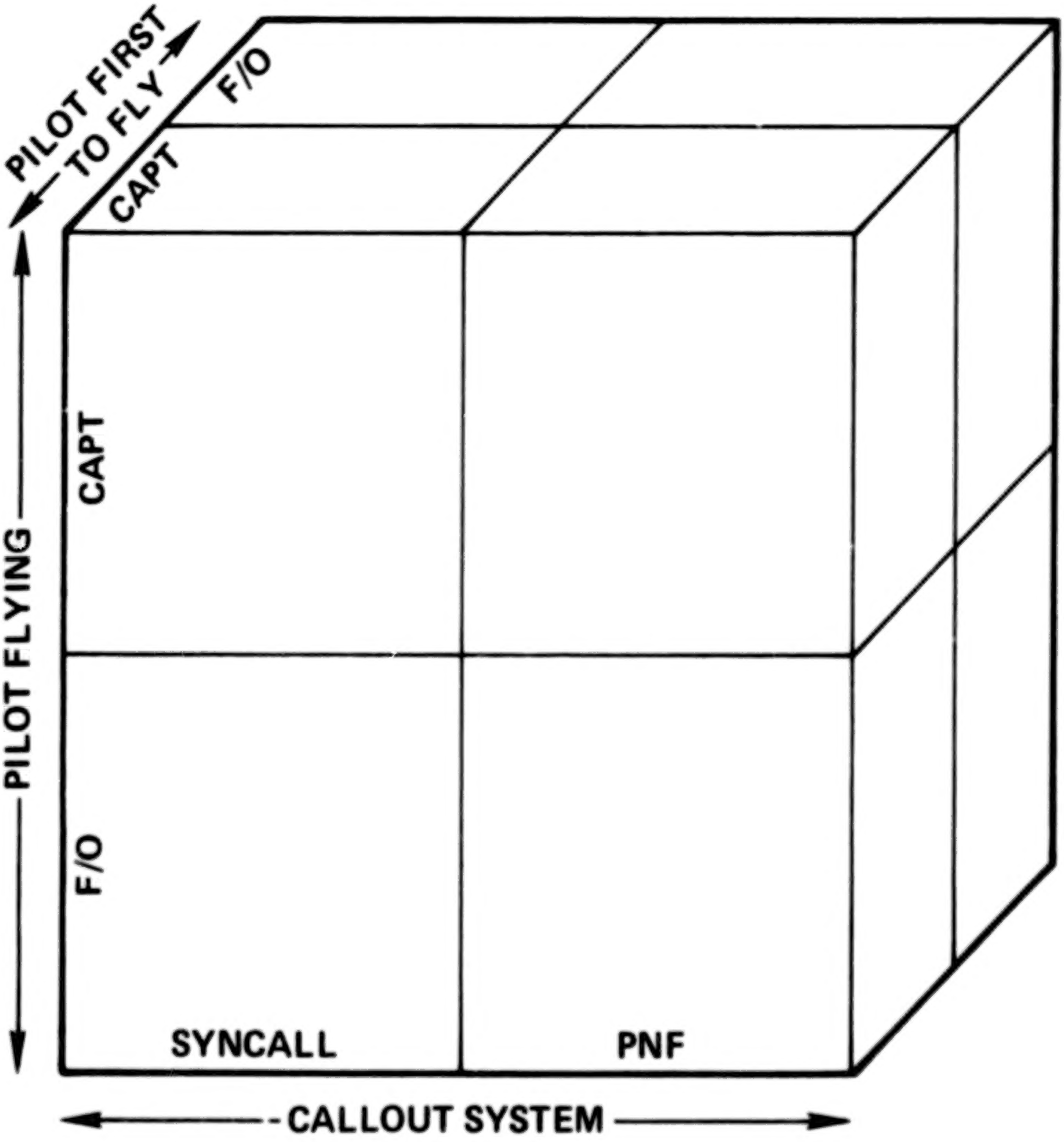
PILOT FIRST TO FLY
F/O
CAPT
CAPT
PILOT FLYING
F/O
SYNCALL
PNF
CALLOUT SYSTEM

Figure 3. - Design for Analysis of Variance for Individual Approaches.

TABLE 16. AIRSPEED PERFORMANCE FOR LOCALIZER BACK COURSE APPROACH DURING SEGMENT IV: MDA TO LANDING/GO-AROUND

CALLOUT SYSTEM	MEAN PERCENT TIME OUT OF TOLERANCE	NUMBER OF APPROACHES OUT OF TOLERANCE
SYNCALL (19 APPROACHES)	13 %	5
PILOT-NOT-FLYING (17 APPROACHES)	34 %	12

in airspeed performance at 500 AFL that was associated with type of callout system, by the time MDA was reached, airspeed performance with SYNCALL was better than with PNF callouts only. Figure 10 graphs the mean airspeed deviation from Selected Approach Speed at 500 AFL and at MDA for SYNCALL and PNF approaches. Average airspeed deviation for PNF approaches tends to increase slightly (+6.5 KTS +/-4.9 KTS at 500 AFL increasing to +7.9 KTS +/-4.3 KTS by MDA). In contrast, average airspeed deviation for SYNCALL approaches tends to decrease (+6.3 KTS +/-3.9 KTS at 500 AFL decreasing to +4.6 KTS +/-3.2 KTS by MDA) Analysis of Variance yielded no significant effect on average airspeed deviation due to either altitude (500 vs MDA) or callout system (SYNCALL vs PNF), but the probability of an interaction between the two approached significance ($F_{max} = 1.85$, $df = 17$, $p < 0.10$) This analysis taken together with the significant effect on airspeed performance associated with type callout system in the lower segment from MDA to Landing or Go-Around suggests that airspeed performance improved during the descent when SYNCALL was in use but did not improve during the same part of the descent when only the PNF callouts were in use.

Sink Rate Deviations During the VOR Approach

Table 18 shows the sink rate data for Segment III (500 AFL to MDA) for the VOR Raw Data Approach. Analysis of Variance for effects of callout system, pilot flying, and order of pilot flying on sink rate performance for this approach yielded a significant difference ($F=5.01$; $df=1,31$; $p<0.05$) due to callout system on the maximum deviation beyond operational tolerance. The effect of callout system on percent time out of tolerance approached significance ($F=4.06$; $df=1,31$; $p=0.053$) When SYNCALL was in use, there were no instances for the 19 approaches flown with SYNCALL of sink rate exceeding the operational tolerance of 1174 FPM. Of the 19 approaches flown with PNF callouts 4 had sink rate deviations in excess of tolerance. The mean maximum deviation of

MEAN AIRSPEED DEVIATIONS FOR LOCALIZER BACK COURSE APPROACH

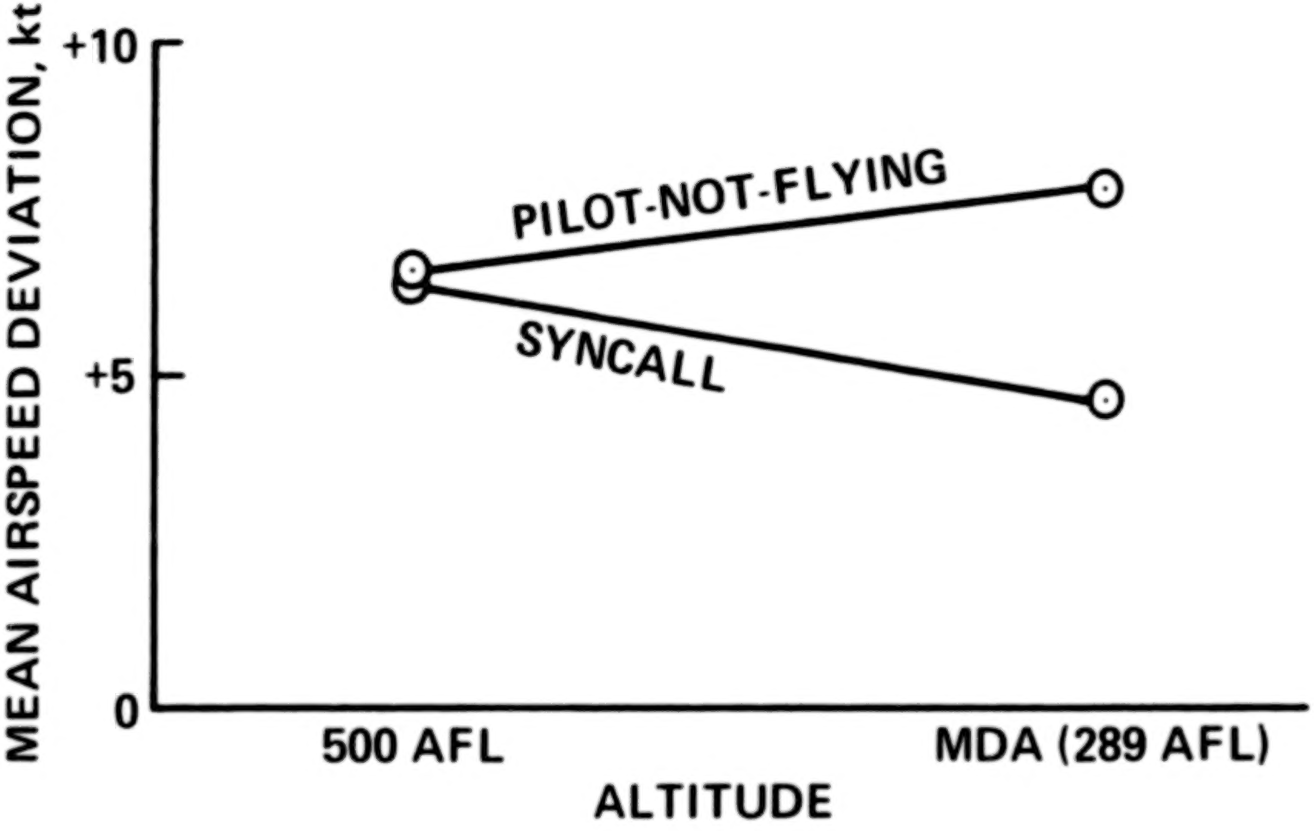

Figure 10. - Mean Airspeed Deviations for Localizer Back Course Approach.

TABLE 17a. NUMBER OF APPROACHES INSIDE AND OUTSIDE TOLERANCE FOR AIRSPEED DURING LOCALIZER BACK COURSE APPROACH AT 500 FEET AFL

	SYNCALL	PILOT-NOT-FLYING
INSIDE TOLERANCE	12	10
OUTSIDE TOLERANCE	7	7

Note: Data were available for only 36 of the 40 approaches flown since 3 approaches terminated in a go-around before the aircraft reached MDA and since data were not available for a 4th approach.

TABLE 17b. NUMBER OF APPROACHES INSIDE AND OUTSIDE TOLERANCE FOR AIRSPEED DURING LOCALIZER BACK COURSE APPROACH AT MDA (= 289 FEET AFL)

	SYNCALL	PILOT-NOT-FLYING
INSIDE TOLERANCE	16	8
OUTSIDE TOLERANCE	3	9

these four "out-of-tolerance" approaches was 1412 FPM +/-167 FPM or 238 FPM beyond the operating tolerance of 1174 FPM. Percent time out of tolerance for all approaches together including those that were always within tolerance was 0 % for SYNCALL approaches compared to 9% for PNF approaches. Finally, for those 4 PNF approaches that were out of tolerance the mean percent time out of tolerance was 37.3%.

1-Engine Approach and Landing Airspeed Performance

As stated above, the 1-Engine Approach and Landing is flown by Captains only and thus had to be analyzed separately. It also differs from other types approaches in the procedures for airspeeds to be flown at various segments of the approach. The other approaches are flown from 1000 feet to landing using Approach Speed, abbreviated V(APPR). 6 On aircraft equipped with

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6. The pilots compute this mentally by adding one half the

TABLE 18. SINK RATE PERFORMANCE FOR VOR RAW DATA APPROACH DURING SEGMENT III: 500 FEET AFL TO MDA (435 FEET)

CALLOUT SYSTEM	NUMBER OF APPROACHES OUT OF TOLERANCE	MEAN MAXIMUM DEVIATION
SYNCALL (19 APPROACHES)	0	---
PILOT-NOT-FLYING (19 APPROACHES)	4	1412 FPM +/- 167 (FOR 4 APPROACHES)

an Auto Throttle System (ATS), like the one simulated in this study, the pilots set an orange airspeed command bug on their airspeed indicators to their chosen V(APPR). They then use this bug to visually assist them if flying manually; also, the ATS, if engaged, will automatically maintain this commanded airspeed. A callout of airspeed referenced to Approach Speed is made at 500 AFL as a cross check. For the 1-Engine Approach, Approach Speed is defined differently. It is the 0 deg flaps/slats extended minimum maneuvering speed for the landing gross weight of the aircraft, abbreviated V(0 deg/EXT). This higher approach speed is maintained until a visual landing commit point of 700 feet AFL in case the crew should have to make a go-around and thus need the added speed for a climb-out with only one engine. If they decide a landing can be assured from 700 AFL then the Captain begins to reduce airspeed so as to arrive at 100 AFL with a speed of V(Ref) plus the conventional wind additives of one half runway wind speed plus gust velocity. The orange command airspeed bug is left at the higher Approach Speed of V(0 deg/EXT) for the duration of the approach. Thus, in contrast to other types of approaches, the pilot now attemps to fly an airspeed well below that indicated by the orange bug, 10 to 20 KTS in the aircraft simulated for this study.

The pilot-not-flying in this instance knows that the captain will be reducing airspeed below the approach speed shown by the orange bug and makes allowance for this when calling out routine airspeed checks or when making an airspeed deviation callout. The SYNCALL system, on the other hand, obtains its Approach Speed setting from the orange ATC command bug setting. Thus, when the

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headwind plus the added speed factor of gusts to V reference with the restriction that Approach Speed will never be less than V(Ref) plus 5 KTS or greater than V(Ref) plus 20 KTS.

captain slows the aircraft to the slower approach speed, the SYNCALL system would be inappropriately triggered to make an airspeed deviation callout.

In order to determine whether such inappropriate deviation callouts had an adverse effect on airspeed performance during the Single Engine Approach and Landing, airspeed was measured referenced to the desired approach speed of V(Ref) + wind when the aircraft was at 100 feet AFL, the point at which procedures call for the speed to be at this slower approach speed. Airspeed performance would be adversely affected if, for the SYNCALL approaches, airspeed was excessively above V(Ref) + wind as compared to the PNF approaches. Table 19 shows mean Indicated Airspeed (IAS) minus V(Ref) + wind additives at 100 AFL for the 10 approaches with SYNCALL and the 9 approaches with PNF callouts. While SYNCALL approaches averaged 9.4 KTS above the desired approach speed and PNF approaches averaged only 6.5 KTS above approach speed, this difference, when tested for statistical significance by T-Test was not significant ($T=1.01$, $df=17$, $p>0.10$). Also, the number of approaches that were flown outside tolerance were almost equal with SYNCALL and with PNF callouts: 4 out of 10 approaches out of tolerance with SYNCALL compared to 5 out of 9 approaches out of tolerance with PNF callouts. However, the standard deviation of the airspeed performance with PNF callouts was only +/-3.6 KTS compared to +/-7.8 KTS for the airspeed performance with SYNCALL. This difference in variability of airspeed performance was significant by two-tailed test for differences between independent variances ($F=4.69$; $df=9,8$; $p<0.05$) Thus the captains' airspeed at 100 feet during the Single-Engine Approach and Landing was more variable with SYNCALL than with PNF callouts. This is certainly an adverse effect on airspeed performance from an operational standpoint.

TABLE 19. AIRSPEED PERFORMANCE FOR 1-ENGINE APPROACH
AND LANDING - CAPTAIN ONLY
AIRSPEED MEASURED AT 100 FEET AFL

CALLOUT SYSTEM	MEAN AIRSPEED DEVIATION	STANDARD DEVIATION
SYNCALL (10 APPROACHES)	+ 9.4 KTS	+/- 7.8 KTS
PILOT-NOT-FLYING (9 APPROACHES)	+ 6.5 KTS	+/- 3.6 KTS

Summary of Individual Approach Results

In summary, there were specific instances of improved performance on airpseed and sink rate when SYNCALL was in use for the non-precision approaches. However, when SYNCALL made inappropriate airspeed deviation callouts for the 1-Engine Approach, airspeed performance became more variable and there was a trend for the pilot-flying to erroneously heed the inappropriate callout.

SYNCALL And Pilot-Not-Flying Callout Performance

The cockpit audio recordings for ten of the twenty crews were analyzed to obtain several types of data. The ten crews were chosen such that half the crews had flown with SYNCALL first and therefore with Approach Set 1, and the other half had flown with SYNCALL last and therefore with Approach Set 2. Each callout made either by the SYNCALL system or by a crew member was transcribed. When both SYNCALL and PNF callouts were made for a given [illegible], the relative order of the two callouts was noted. For the approaches flown using PNF callouts, the audio of the SYNCALL system had been turned off in the cockpit. However, the SYNCALL system continued to function, albeit silently as far as the crew was concerned. These callouts made by SYNCALL were recorded on audio tape mixed with the ongoing cockpit audio for the PNF approaches. Thus it was possible to determine, for the PNF approaches, whether SYNCALL would have made a given callout, had it been operational and to compare the reliability of SYNCALL to PNF callouts in terms of 1) whether a given callout was made or not and 2) which system made the callout first: SYNCALL or PNF.[7] Finally, a tabulation was made of other concurrent audio events that occurred in the cockpit when SYNCALL callouts would have been made for the approaches that used PNF callouts.

Reliability of Callouts

Table 20 shows the reliability of PNF and of SYNCALL for making normal approach callouts in the simulator. For the 53 approaches for which PNF callouts were used, a total of 746 callouts were required. 537 of these or 72% were made by the Pilot-not-Flying. For the 53 approaches with SYNCALL, a total of 585 normal callouts were required.[8] 509 of these or 87% were made by SYNCALL. It should be noted that there were no approaches for which no callouts at all were made, for either system. Rather, for some approaches not all the callouts were made, and this was true for both systems. The difference in number of callouts made by SYNCALL and by PNF was significant (X(2)=91.24, df=1, p<0.002).

Since any conclusions regarding the relative reliability of a

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[7] This ingenious idea was the suggestion of Gene Tomlinson, simulation computer programmer for the project.

[8] The difference of 746 required callouts the 53 PNF approaches compared to the 585 required callouts for the 53 SYNCALL approaches resulted from the differences in go-around altitudes used by different pilots for those approaches that were terminated in go-arounds. For example, a go-around at 450 feet would require altitude callouts only to 500 feet while a go-around at 150 feet would require altitude callouts all the way down to 200 feet.

TABLE 20. RELIABILITY OF SYNCALL AND OF PILOT-NOT-FLYING FOR MAKING NORMAL APPROACH CALLOUTS IN THE SIMULATOR

CALLOUT SYSTEM	WAS CALLOUT MADE ? YES	NO	TOTAL	PERCENT
SYNCALL (53 APPROACHES)	509	76	585	87 %
PILOT-NOT-FLYING (53 APPROACHES)	537	209	746	72 %

system like SYNCALL compared to Pilot-not-Flying callouts were to be made on the basis of data collected in a simulation of actual flight, the reliability of PNF callouts in the simulator was compared to the reliability of PNF callouts in the actual aircraft on the line. This comparison could only be performed for normal callouts and could not be done for matched sets of approaches since most approaches flown on the line are flown in visual weather conditions even if by instrument procedures. By contrast, all but the single-engine approach in the simulator are flown with simulated instrument weather conditions down to decision height or MDA. If anything, however, this should tend to make PNF callout reliability on the line lower than in the simulator, if low callout reliability is associated with better weather conditions on the approach. Table 21 shows the reliability of normal PNF callouts being made on the line and in the simulator with 79% of the normal callouts made on the line compared to 72% of the normal callouts made in the simulator. The difference in the number of callouts made in each case was significant ($X(2)=9.91$, $df=1$, $p<0.002$) with the normal callouts on the line actually being more reliably made than the normal callouts made in the simulator during the experiment. Thus, if anything, PNF normal callouts would be expected to be closer in reliability to SYNCALL normal callouts when made on the line during actual flight operations.

In an attempt to make the line data and the simulator data more comparable, the percentage of normal callouts made under the three conditions: 1) PNF on the line, 2) PNF in the simulator during the experiment, and 3) SYNCALL in the simulator during the experiment were re-calculated, deleting from consideration all the MDA and DH callouts, since these were rarely required on the line due to the good weather (4 of the 54 line approaches were flown in weather close to the published minimums). Table 22 shows the resulting percentages with the previous percentages

TABLE 21. RELIABILITY OF PILOT-NOT-FLYING ON THE LINE AND IN THE SIMULATOR FOR MAKING NORMAL APPROACH CALLOUTS FROM 1000 FEET AFL TO 100 FEET RADIO ALTIMETER

	WAS CALLOUT MADE ? YES	NO	TOTAL	PERCENT
ON THE LINE (54 APPROACHES)	696	189	885	79 %
IN THE SIMULATOR (53 APPROACHES)	432	172	604	72 %

that did include MDA and DH callouts, for comparison. No statistical analysis of this three-way comparative data was performed since the validity of such a comparison is doubtful. Rather, it is simply interesting to note that the 83% reliability of PNF normal callouts on the line would appear to be very close to the 85% reliability of SYNCALL normal callouts in the simulator. And this in turn brings into question the importance of the statistically significant difference between PNF and SYNCALL normal callout reliability in the simulator. This point will be discussed further in the Discussion section.

TABLE 22. RELIABILITY OF NORMAL APPROACH CALLOUTS MADE BY PILOT-NOT-FLYING ON THE LINE AND IN THE SIMULATOR AND BY SYNCALL IN THE SIMULATOR

	MDA & DH CALLOUTS INCLUDED	EXCLUDING MDA & DH CALLOUTS
ON THE LINE	79 %	83 %
PNF IN THE SIMULATOR	72 %	74 %
SYNCALL IN THE SIMULATOR	87 %	85 %

The reliability of the deviation callouts made by SYNCALL and by PNF is shown in Table 23. While SYNCALL was designed to repeat a deviation callout if the problem was not corrected, for purposes of analysis, such repetitions were scored as belonging to the same instance of a required callout. Thus, if for a given deviation, the callout system made one or more callouts, that required callout was scored as having been made once. It was noted that SYNCALL repeated deviation callouts for a given deviation far more frequently than did the PNF and this was the main reason for the chosen method of counting number of callouts made.

TABLE 23. RELIABILITY OF DEVIATION CALLOUTS BY SYNCALL AND BY PILOT-NOT-FLYING IN THE SIMULATOR

CALLOUT SYSTEM	WAS CALLOUT MADE ? YES	NO	TOTAL	PERCENT
SYNCALL	75	8	83	90 %
PILOT-NOT-FLYING (SYNCALL OFF)	39	50	89	49 %

Data are totals from 53 approaches for each callout system.

When PNF deviation callouts were used, 49% of the instances requiring deviation callouts had deviation callouts made by the pilot-not-flying. This is compared to 90% of the instances requiring deviation callouts for which callouts were made by the SYNCALL system when it was in use. The difference in numbers of callouts made by the two systems was significant (X(2)=41.63, df=1, p<0.002).

Table 24 shows the number of deviation callouts made by the pilot-not-flying when SYNCALL was not in use compared to the number of deviation callouts made by the pilot-not-flying when SYNCALL was operational. The PNF made only 24% of the required deviation callouts when SYNCALL was also making deviation callouts, compared to 49% of the required deviation callouts when he had sole responsibility for making these callouts. This difference in numbers of callouts made in the two conditions was also significant (X(2)=7.41, df=1, p<0.01) Thus, while SYNCALL was far more reliable than PNF for making deviation callouts, SYNCALL also seems to have decreased the reliability of the PNF callouts themselves even though the pilots were instructed to make deviation callouts if required when SYNCALL was in use and even though SYNCALL was designed with larger tolerances than those used by the pilot-not-flying.

Table 25 lists the individual normal callouts with the numbers of each that were or were not made by PNF in the simulator, by SYNCALL in the simulator, and for comparison, by PNF on the line. The asterisks indicate those callouts for which there

TABLE 24. RELIABILITY OF DEVIATION CALLOUTS BY PILOT-NOT-FLYING WITH SYNCALL AND WITH NO SYNCALL

	WAS CALLOUT MADE ? YES	NO	TOTAL	PERCENT
PILOT-NOT-FLYING WITH SYNCALL	20	63	83	24 %
PILOT-NOT-FLYING NO SYNCALL	39	50	89	49 %

Data are totals from 53 approaches for each condition.

was a significant difference ($p < 0.01$) between the number of callouts made by SYNCALL and by PNF in the simulator. The callouts for which SYNCALL was more reliable than PNF appear to fit into certain categories:

Critical Descent Altitudes
  Decision Height
  MDA
  100 above MDA
  Outer Marker crossing altitude

Flight Path position
  Localizer Intercept
  Glideslope Intercept

Routine read-out of performance values
  IAS at 500 feet
  Sink Rate at 500 feet

Ten-foot altitude callouts
  50
  40
  30
  10

* The difference for the 20 foot callout could not be tested since two cells of the Chi-Square had expected values less than 5.

Finally, it is interesting to note that both in the simulator and on the line, the PNF makes a 100 foot callout with fair reliability, 73% in the simulator and 98% on the line compared to 77% by SYNCALL. This is particularly interesting since the flight

TABLE 25. RELIABILITY OF INDIVIDUAL NORMAL APPROACH CALLOUTS MADE BY SYNCALL AND BY PILOT-NOT-FLYING IN THE SIMULATOR AND ON THE LINE

	IN SIMULATOR							ON THE LINE		
	PNF				SYNCALL			PNF		
CALLOUT	YES	NO	%	sig?	YES	NO	%	YES	NO	%
LOC INT	14	29	33	*	39	0	100	-	-	-
G/S INT	26	7	79	*	30	1	97	-	-	-
O M	23	10	70	*	32	1	97	-	-	-
O M ALT	12	21	36	*	32	1	97	-	-	-
1000 FEET	50	2	96		51	1	98	55	9	86
500 FEET	45	6	88		44	8	85	57	6	90
IAS @ 500	27	20	57	*	44	8	85	38	26	59
SNK @ 500	30	19	61	*	44	8	85	27	37	42
400	30	22	58		32	19	63	49	14	78
300	34	12	74		35	17	84	55	3	95
200	34	13	72		23	16	59	55	9	86
100	24	9	73		20	6	77	56	8	88
100+MDA	15	7	68	*	21	0	100	0	1	0
MDA or DH	10 15	11 14	48 52	* *	21 25	0 0	100 100	0 3	1 60	0 5
50	25	9	74	*	25	0	100	59	5	92
40	24	9	73	*	25	0	100	56	8	88
30	23	8	74	*	24	0	100	50	4	94
20	25	5	83		21	0	100	52	2	97
10	23	6	79	*	19	0	100	53	1	98

manual for the participating airline does not call for a 100 foot callout. None-the-less, the author in designing the SYNCALL system and the line pilots both in the airplane and in the simulator appear to have generalized the concept of 100-foot callouts to include a callout at 100 feet.

Relative Timing of Normal Callouts made by PNF and by SYNCALL

Table 26 shows the relative timing of normal callouts made by PNF compared to those that would have been made by SYNCALL for the PNF callout approaches. Of all 746 callouts that were required, 5% were/would not have been made by SYNCALL, compared to 25% that were not made by PNF. 8% of the required callouts were not made by either system. When both the PNF callout was made and the SYNCALL callout was/would have been made, a total of 62% of the callouts, the distribution was closely balanced between the PNF callout coming first (24%) and the SYNCALL callout coming first (29%) with a few instances of the two callouts being started simultaneously (9%).

TABLE 26. RELATIVE TIMING OF NORMAL APPROACH CALLOUTS MADE BY PILOT-NOT-FLYING COMPARED TO SAME CALLOUTS MADE BY SYNCALL FOR 53 APPROACHES. THE CREW DID NOT HEAR THE SYNCALL CALLOUTS. NORMAL CALLOUT PROCEDURES WERE USED

	NUMBER	PERCENT
MISSING SYNCALL CALLOUT	41	5 %
PNF CALLOUT BEFORE SYNCALL	182	24 %
PNF CALLOUT SAME TIME AS SYNCALL	56	9 %
PNF CALLOUT AFTER SYNCALL	216	29 %
MISSING PNF CALLOUT	184	25 %
NO CALLOUT BY EITHER SYNCALL/PNF	57	8 %
TOTAL NUMBER OF CALLOUTS	745	100 %

Other audio information that overlapped SYNCALL callouts

Table 27 shows the percentages of SYNCALL callouts that occurred at the same time as various other types of audio information. Again, the data was taken from the approaches for which PNF callouts were in use and SYNCALL callouts were recorded on the audio tape only, not heard in the cockpit. 50% of the SYNCALL callouts did occur/would have occurred at the same time as some other audio information. The interference with ATC communications between the controller and the simulated flight was minimal (3% of the crew's transmissions to ATC and 3% of ATC's transmissions to the crew. The overlap with other ATC chatter was higher (13%) but probably acceptable since pilots only occasionally report learning useful information from listening to background ATC chatter (such as routing to expect and, occasionally critical traffic information). However, 23% of the callouts would have occurred during crew checklists and other callouts. This relatively large percentage could have masked either the

SYNCALL callout or the crew voice message, had it actually occurred.

In contrast, the Pilot-not-Flying when making Approach Callouts was observed to sequence these with other crew checklist calls so as to minimize overlap. Like SYNCALL, however, the PNF callouts often overlapped with Other ATC.

TABLE 27. PERCENT OF SYNCALL CALLOUTS WHICH WERE OVERLAPPED WITH OTHER, SIMULTANEOUS COMPETING AUDIO INFORMATION

CREW TO ATC	3 %
ATC TO CREW	3 %
OTHER ATC	18 %
CREW CHECKLISTS/CALLS	23 %
OTHER SOUNDS	3 %
NO OVERLAP	50 %

Timing Accuracy of Ten-Foot Callouts by SYNCALL

Figure 11 shows the minimum, average, and maximum errors in the timing of ten-foot callouts made by SYNCALL in terms of the difference between the called altitude and the actual aircraft altitude when the callout started. The altitude errors are shown as a function of sink rate. Thus, the higher the rate of descent, the less timely is the information given by a ten-foot callout. For example, with a sink rate of 200 FPM, the ten-foot callout for 30 feet would, on the average, start when the aircraft had actually descended to 27.5 feet. For a sink rate of 1000 FPM, the same callout would start, on the average, when the aircraft had descended to 21.5 feet. Thus for high rates of descent ten-foot callout altitude information by SYNCALL was not timely. Figures 12, 13, and 14 contain the actual data points from which the three curves were derived. The timeliness of the corresponding PNF callouts can be inferred by examining the relative timing of each PNF ten-foot callout with that of the corresponding SYNCALL ten-foot callout and tabulating these relative time categories (Before, Same Time As, After) for different levels of sink rate. When this analysis was done, no systematic relationship was found, suggesting factors other than sink rate for the timeliness of PNF 10-foot callouts.

Inappropriate Callouts by SYNCALL

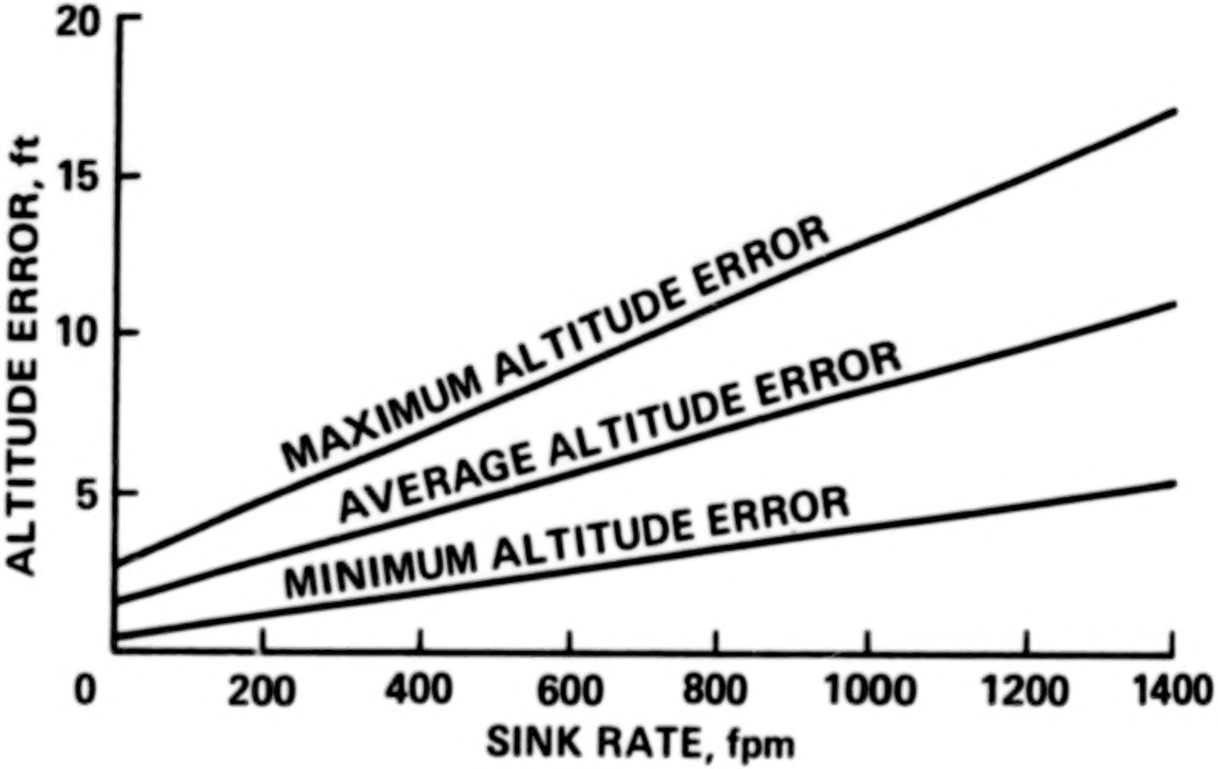
Certain callouts were made by the SYNCALL system at inappropriate times or contained inappropriate information. Most of these were artifacts related to the instructional aspects of flying approaches in a flight simulator. For example, pilots heard an immediate "Localizer Intercept", each time the simulator position was reset to a position on the localizer track. Another anomaly was the message "100 feet above MDA" if the instructor pilot used the altitude reset capability. These problems would not be expected in an actual aircraft.

Other SYNCALL callouts were made occasionally for situations which had been unintended in the design of the system. Unlike the inappropriate callouts listed above, these had some relevance to the current flight situation, and, in fact, some of the pilots upon hearing them remarked that they gave useful information. SYNCALL called out the Outer Marker and crossing altitude any time the aircraft passed over the outer marker while being vectored by ATC. "Localizer Intercept" was called out any time the aircraft was vectored through the localizer at an altitude less than 3000 AFL. Localizer deviation callouts were then made following such unintended localizer intercept callouts. While the pilots found the unintended localizer intercept callouts useful, the ensuing deviation callouts were generally perceived as a nuisance.

Finally, there was one instance of SYNCALL callouts that were not only inappropriate but which, while giving true information, presented this information in a way which implied exactly the opposite of the intended message to the crew. This was the case of airspeed deviation callouts which called airspeed as being excessively slow when in fact the pilot-flying was purposely slowing the aircraft. for the single-engine approach, discussed above in the section on flight performance results.

Callouts Made by PNF But Not SYNCALL

During the experiment, it was observed that the Pilot-not-Flying made other callouts appropriate and useful to the approach that the SYNCALL system had not been designed to make. Some of these had been purposely omitted from SYNCALL system design to avoid nuisance callouts. One such was deviation callouts right or left of VOR course. The simulator Course Deviation Indicator (CDI) did not distinguish Localizer and VOR signals; thus no difference in sensitivity for course deviation callouts could be programmed for VOR course deviations as compared to Localizer course deviations. The PNF did however, take this difference into account when making deviation callouts during the VOR approach. SYNCALL was purposely designed to make airspeed and sink rate deviation callouts only between 500 and 100 feet AFL to avoid nuisance callouts. The PNF, however, occasionally judged it necessary to make such callouts above or below this altitude range. The result of the inappropriate negative airspeed devia-



ALTITUDE ERROR OF TEN-FOOT CALLOUTS BY SYNCALL AS A FUNCTION OF SINK RATE

(AT LEAST 5 SAMPLES PER DATA POINT)

Figure 11. - Altitude Error of Ten-Foot Callouts by SYNCALL as a Function of Sink Rate.

MINIMUM ALTITUDE ERROR BY SINK RATE FOR TEN-FOOT CALLOUTS BY SYNCALL

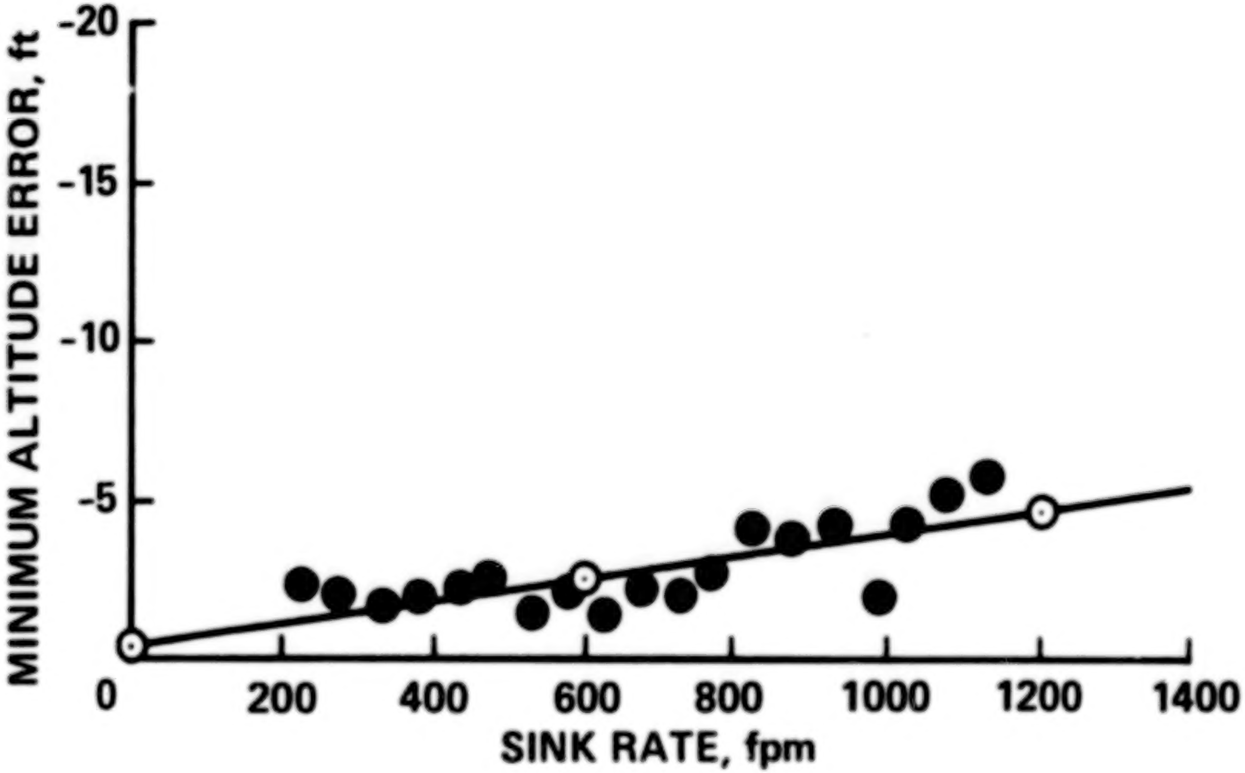


Figure 12. - Minimum Altitude Error by Sink Rate for Ten-Foot Callouts by SYNCALL.

MEAN ALTITUDE ERROR BY SINK RATE FOR TEN-FOOT CALLOUTS BY SYNCALL

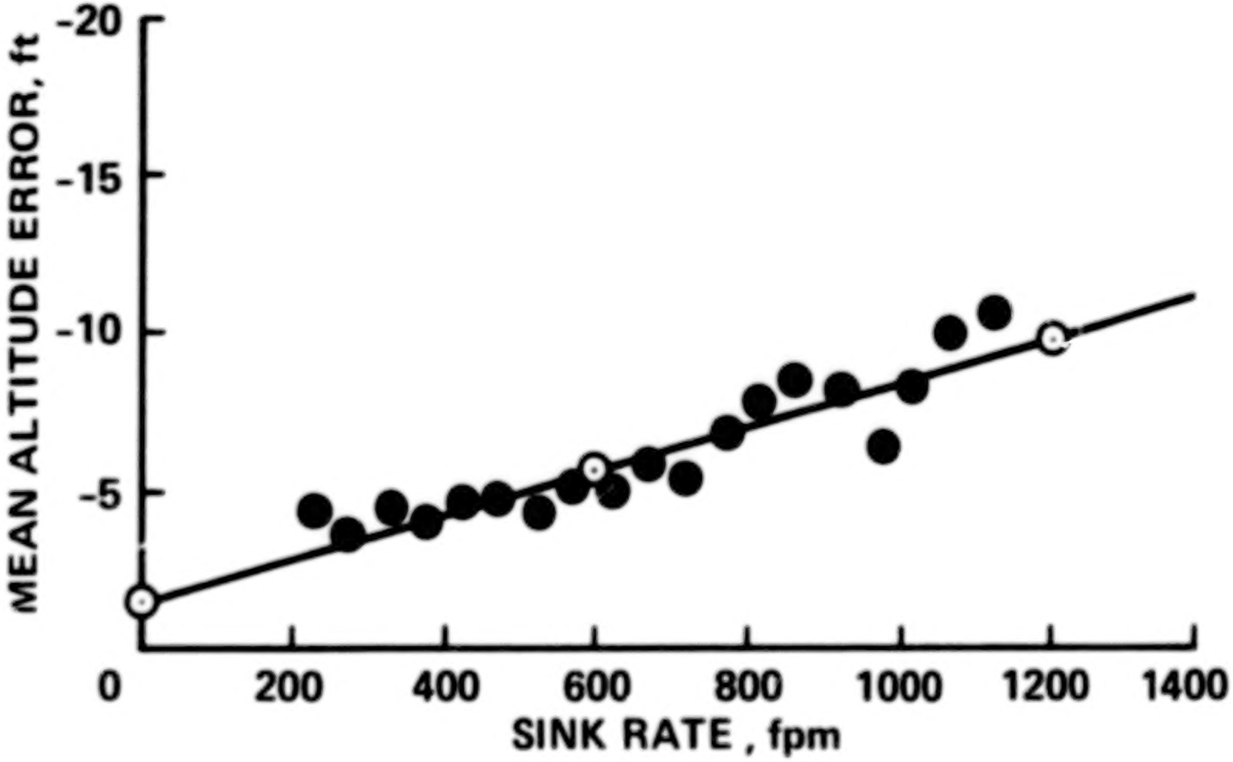


Figure 13. - Mean Altitude Error by Sink Rate for Ten-Foot Callouts by SYNCALL.

MAXIMUM ALTITUDE ERROR BY SINK RATE FOR TEN-FOOT CALLOUTS BY SYNCALL

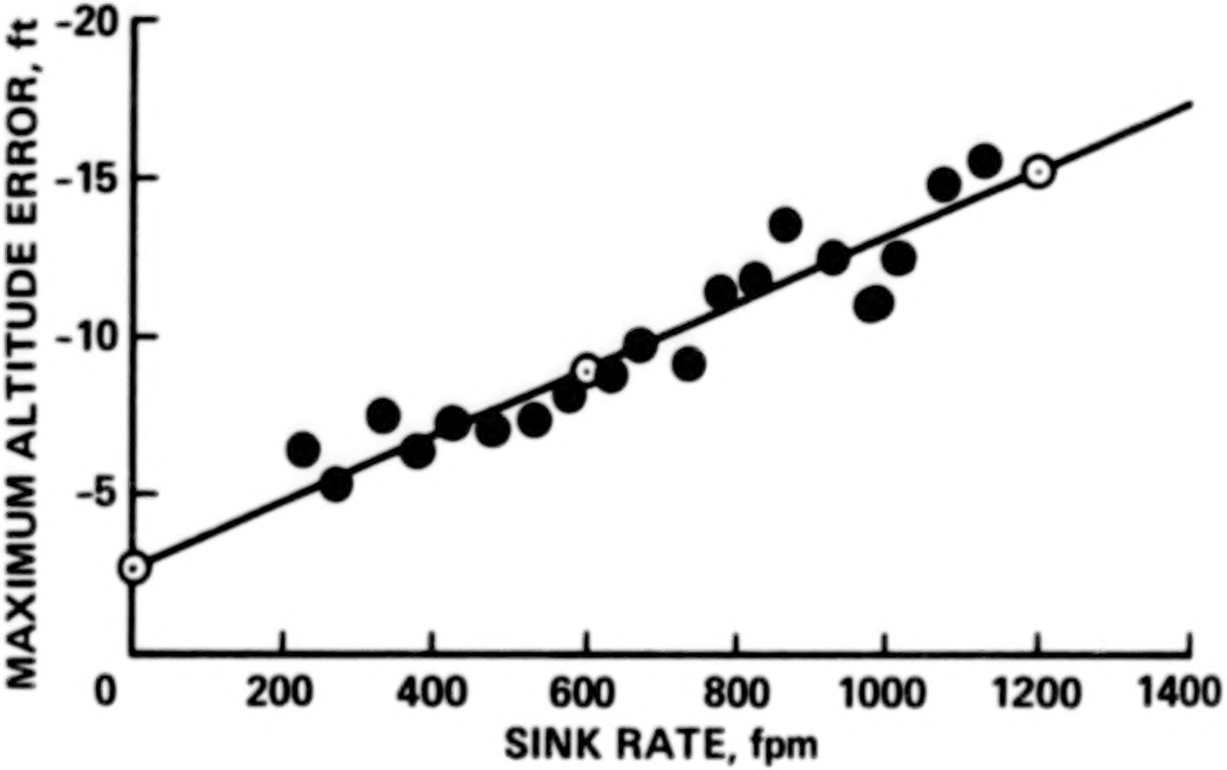


Figure 14. - Maximum Altitude Error by Sink Rate for Ten-Foot Callouts by SYNCALL.

tion callouts during the single-engine approach was often positive airspeed deviation callouts by the PNF, reflecting the actual situation if it appeared that the pilot-flying was erroneously heeding the SYNCALL messages and not slowing the aircraft. Finally, the PNF called out "Below MDA" or "Above MDA" if either occurred after reaching MDA but before the runway was in sight. Since SYNCALL had no information about visual acquisition of the runway it would have been unable to make such callouts appropriately.

Summary of Callout Performance Data

SYNCALL was more reliable than PNF for making deviation callouts and also for making normal callouts. However, comparison with line data for normal callouts suggests that the PNF normal approach callouts on the line would be close in reliability to those made by SYNCALL. SYNCALL systematically missed certain callouts that were made by PNF, and neither system made all the callouts. Crew communications with ATC had minimal overlap with SYNCALL, however, a relatively large percentage of SYNCALL callouts overlapped crew checklist and callout messages.

Pilot Judgment Data

Table 28 shows the percent of the 40 pilots who found each category of callout by SYNCALL (normal and deviation) "useful and desirable" for each of the four types of approach conditions. Nearly all (85%) of the pilots who flew SYNCALL during this evaluation wanted the system to make normal altitude callouts during approaches when the weather was down to IFR minimums. 73% wanted SYNCALL to make deviation callouts under these same conditions. For the other conditions, the percent of pilots who wanted SYNCALL callouts of the two types ranged from 49% for deviation callouts during Day VFR conditions to 78% for normal altitude callouts during abnormal or emergency conditions. For N=40 pilots, Chi-sqaure analysis with 1 degree of freedom yields $p<0.01$ for any condition in which 71% or more pilots wanted SYNCALL. Thus the data support a strong pilot preference for SYNCALL during approaches with IFR weather, or with abnormal or emergency conditions. For night VFR conditions, only normal altitude callouts received this strong preference. There is no such preference for SYNCALL during day VFR operations.

TABLE 28. PERCENT OF PILOTS WHO FLEW SYNCALL THAT WANTED IT TO MAKE NORMAL CALLOUTS AND OR DEVIATION CALLOUTS FOR FOUR TYPES OF APPROACH CONDITIONS. N = 40 PILOTS (20 CAPTAINS AND 20 FIRST OFFICERS)

	APPROACH CONDITION			
	NIGHT VFR	ABNORMAL/ EMERGENCY	DAY VFR	IFR TO MINIMUMS
NORMAL ALTITUDE CALLOUTS (10 TYPES)	71 %	78 %	57 %	85 %
DEVIATION CALLOUTS (4 TYPES)	56 %	69 %	49 %	73 %
MEAN FOR ALL CALLOUTS	67 %	75 %	55 %	82 %

TABLE 29. PERCENT OF PILOTS WHO FLEW SYNCALL THAT WANTED THE PILOT-NOT-FLYING TO MAKE NORMAL CALLOUTS AND OR DEVIATION CALLOUTS FOR FOUR TYPES OF APPROACH CONDITIONS
N = 40 PILOTS (20 CAPTAINS AND 20 FIRST OFFICERS

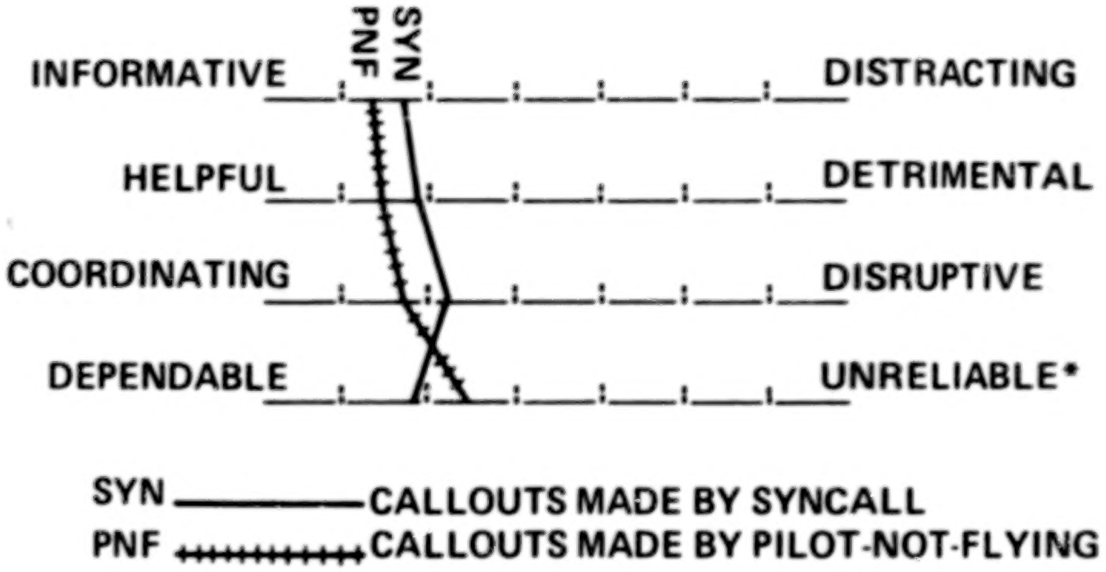
	APPROACH CONDITION			
	NIGHT VFR	ABNORMAL/ EMERGENCY	DAY VFR	IFR TO MINIMUMS
NORMAL ALTITUDE CALLOUTS (10 TYPES)	57 %	68 %	51 %	68 %
DEVIATION CALLOUTS (4 TYPES)	52 %	67 %	47 %	65 %
MEAN FOR ALL CALLOUTS	54 %	68 %	50 %	67 %

Table 29 shows the corresponding data for Pilot-not-Flying callouts. Using the Chi-Square probabilities from above, there were no conditions that reached the 0.01 level of significance. Thus, the pilots as a group were neither in favor of nor against pilot-not-flying callouts.

Table 30 shows pilots' perceived intelligibility ratings for the synthesized voice compared to the human voice messages of the ATC tapes and of the pilot-not-flying callouts. Interestingly, after this initial exposure, the intelligibility ratings for the synthesized voice were close to those for actual ATC communications. Many pilots noted independently that the electronic voice quality of the synthesizer made it very distinctive and left no doubt regarding the source of the voice.

Figure 15 shows the mean ratings for all callouts on four of the semantic differential scales for each of the callout systems (SYNCALL and PNF). These data come from the 28 of the 40 pilots or 70% who volunteered to complete this optional form on their own time. Differences between ratings for SYNCALL and PNF callouts were significant for all four scales (Informative-Distracting $t=-3.23$, $P<0.05$; Helpful-Detrimental $t=-5.12$, $p<0.002$; Dependable-Unreliable $t=7.98$, $P<0.002$; Disruptive-Coordinating $t=-6.42$, $p<0.002$; $df=8$ for each scale).

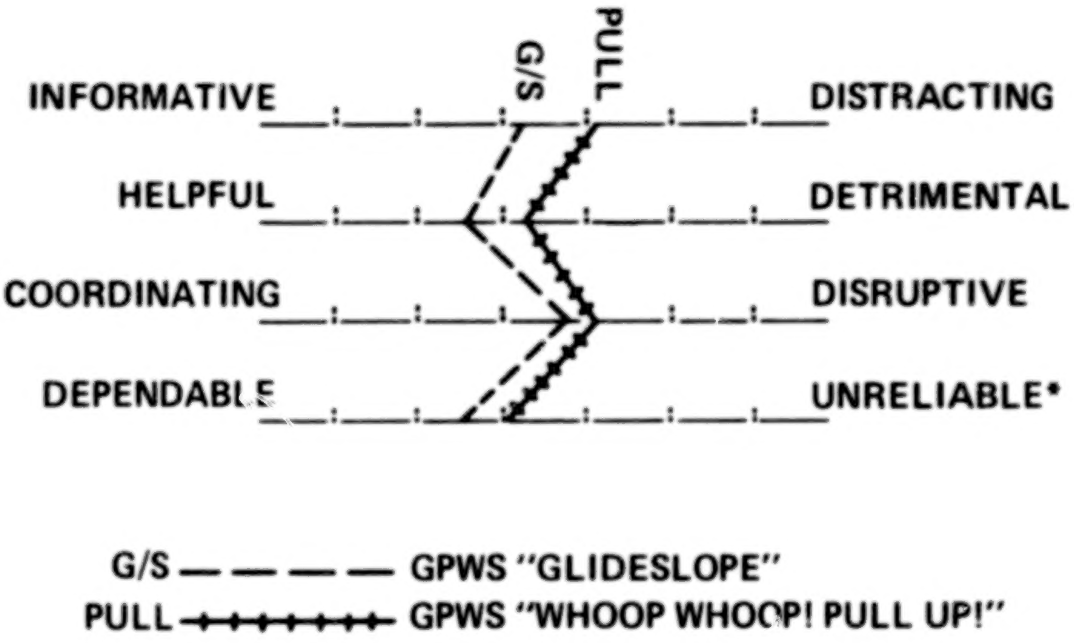
SEMANTIC DIFFERENTIAL RATINGS OF CALLOUTS BY 14 CAPTAINS AND 14 FIRST OFFICERS



*POLARITY OF THIS SCALE IS REVERSED FOR CLARITY OF PRESENTATION. SCALE POLARITY ON DEBRIEFING SHEETS WAS RANDOM.

Figure 15. - Semantic Differential Ratings of Callouts by 14 Captains and 14 First Officers.

SEMANTIC DIFFERENTIAL RATINGS OF THE GPWS "GLIDESLOPE" AND THE GPWS "WHOOP WHOOP! PULL UP!" BY 14 CAPTAINS AND 14 FIRST OFFICERS



*POLARITY OF THIS SCALE IS REVERSED FOR CLARITY OF PRESENTATION. SCALE POLARITY ON DEBRIEFING SHEETS WAS RANDOM.

Figure 16. - Semantic Differential Ratings of the GPWS "Glideslope" and the GPWS "Whoop Whoop! Pull Up!" by 14 Captains and 14 First Officers.

TABLE 30. PERCEIVED INTELLIGIBILITY (PILOT JUDGMENTS) OF DIFFERENT TYPES OF SPEECH HEARD DURING SYNCALL STUDY

SYNCALL (SYNTHESIZED VOICE)	75 %
ATC COMMUNICATIONS (TAPED, LIVE)	76 %
PILOT-NOT-FLYING CALLOUTS	88 %

While both systems were judged as informative, helpful, dependable, and coordinating, callouts given by PNF were judged as more informative, more helpful, and more coordinating than the same callouts by SYNCALL. On the other hand, callouts by SYNCALL were judged as more dependable than the same callouts by PNF.

For purposes of comparison to an existing system that produces voice messages on the approach to landing, the pilots ratings of the GPWS "Whoop, Whoop! Pull Up!" and "Glideslope" messages are given in Figure 16.

The next pilot judgment data was obtained from a follow-up debriefing form that was mailed to the 28 pilots who participated in the optional semantic differential form. Of these, 13 pilots, or 46%, responded in a period from 3 to 9 months after the experiment. The follow-up debriefing form is reproduced in Appendix IV.

Table 31 shows the modal responses for tolerance values for each of the deviation callouts. These pilots' recommendations for sink rate, localizer, and glideslope tolerances matched those of the SYNCALL system as designed for the study. However, their recommendations for airspeed tolerances were different from the SYNCALL tolerance of +/- 7 KTS. They suggested +10 KTS and -5 KTS.

Table 32 shows these pilots' recommendations for active zones for SYNCALL deviation callouts. Their recommendations matched the original design of the SYNCALL system.

Finally, Table 33 shows these pilots' mean and median ratings of the recommended modifications suggested by one or more of the 40 pilots who participated in the study. In the column on the far right is listed, for each recommendation the number of the 13 pilots who judged that recommendation to be "essential in order for you to accept SYNCALL in your cockpit".

TABLE 31. LINE PILOT PREFERENCES FOR SYNCALL DEVIATION CALLOUT TOLERANCES. ALL DATA ARE MODES.

	RECOMMENDED TOLERANCE
AIRSPEED	V (APPR) + 10 OR - 5
SINK RATE	
2000 TO 1000 AFL	2500 FPM
1000 TO 300 AFL	1200 FPM
BELOW 300 AFL	➡ 1000 FMP
LOCALIZER	1/2 DOT
GLIDESLOPE	1 1/3 DOTS

Note: One captain suggested 1 1/2 dots for localizer back course and 2 dots for a VOR approach. Another captain suggested 2 dots glideslope to 500 feet AFL and then 1 dot when below 500 AFL.

TABLE 32. LINE PILOT PREFERENCES FOR SYNCALL DEVIATION CALLOUT REPETITION RATES AND ACTIVE ZONES. ALL DATA ARE MODES

	REPETITION RATE	ACTIVE ZONE
AIRSPEED	5 SEC	600 TO 100 FEET AFL
SINK RATE	5 SEC	500 TO 100 FEET AFL
LOCALIZER	10 SEC	LOC CAPTURE TO 100 FEET AFL
GLIDESLOPE	5 SEC	G/S CAPTURE TO 100 FEET AFL

Note: Five pilots suggested an active zone for glideslope and localizer from approximately 1000 to 100 feet AFL.
N = 13 pilots who responded to second debriefing by mail up to 9 months after having flown SY ALL in the experiment.

TABLE 33. PILOT RATINGS OF THEIR OWN SUGGESTED MODIFICATIONS TO SYNCALL USING THE SCALE:

UNSAFE	UNDESIRABLE	NO PREFERENCE OR CAN'T DECIDE	DESIRABLE	HIGHLY DESIRABLE
5	4	3	2	1

SUGGESTIONS WERE MADE BY ALL 40 PILOTS. RATINGS WERE OBTAINED FROM 13 PILOTS WHO RESPONDED TO SECOND DEBRIEFING BY MAIL UP TO 9 MONTHS AFTER HAVING FLOWN SYNCALL IN THE EXPERIMENT.

SUGGESTION	MEAN	SD	MEDIAN	NUMBER JUDGED ESSENTIAL (N = 13)
OBTAIN FAA & COMPANY AGREEMENT NOT TO USE COCKPIT VOICE RECORDINGS OF SYNCALL FOR DISCIPLINARY ACTIONS	1.17	0.58	1	10
ON/OFF SWITCH	1.23	0.52	1	10
ELIMINATE NUISANCE CALLOUTS	1.40	0.70	1	5
PROVIDE TEST SWITCH	1.54	0.66	1	6
MANUAL VOLUME CONTROL	1.69	0.95	1	5
CALLOUT FOR "BELOW MDA"	2.00	1.15	2	3
INCREASE TOLERANCE ON AIRSPEED DEVIATION CALLOUTS	2.08	1.04	2	4
INHIBIT AIRSPEED AND SINK RATE DEVIATION CALLOUTS DURING ABNORMAL OR EMERGENCY APPROACHES	2.09	1.51	1	4
MINIMIZE FREQUENCY OF DEVIATION CALLOUTS	2.15	0.80	2	2
ELIMINATE GPWS AND REPLACE IT WITH SYNCALL	2.15	0.90	2	3
REPEAT 10-FOOT CALLOUTS IF AIRCRAFT BALLOONS DURING FLARE	2.15	0.90	2	3

WARN IF AIRSPEED IS BELOW ALPHA SPEED	2.17	1.11	2	1
CLARIFY SYNCALL AND PILOT-NOT FLYING RESPONSIBILITIES	2.23	1.09	3	2
CALL LOC CAPTURE AND THEN LOCALIZER INTERCEPT	2.23	0.33	2	1
SHORTEN MESSAGE	2.25	0.75	2	2
SPEED UP SYNCALL SPEECH RATE	2.37	1.19	2	4
ADD OTHER WARNINGS, E.G. ENGINE FIRE, LOSS OF CABIN PRESSURE	2.45	1.20	2	1
AUTOMATICALLY CHANGE SYNCALL PARAMETERS ACORDING TO TYPE OF APPROACH	2.45	1.05	2	2
FOR NON-PRECISION APPROACHES MAKE SINK RATE DEVIATION CALLOUTS HAVE TOP PRIORITY	2.46	1.05	3	2
MORE ALERTING VOICE QUALITY FOR DEVIATIONS THAN FOR NORMAL ALTITUDE CALLOUTS	2.52	0.87	3	2
INCREASE TOLERANCE FOR GLIDESLOPE DEVIATIONS	2.85	0.90	3	2
HAVE SYNCALL SAY "CHECK FLAPS" AT 1000 FEET AFL	3.00	1.00	3	1
HAVE SYNCALL READ OUT FLAPS SETTING AT 1000 FEET AFL	3.00	1.29	4	2
INCREASE TOLERANCE FOR LOCALIZER DEVIATIONS	3.03	0.79	3	1
ADD IMMEDIATE ACTION CHECKLIST ITEMS	3.03	1.32	4	1
HAVE SYNCALL MAKE DEVIATION CALLOUTS ONLY	3.09	1.14	4	0
HAVE SYNCALL READ OUT FLIGHT GUIDANCE SYSTEM MODES AFTER LAND MODE IS ARMED	3.15	0.99	3	1

DELAY CALLOUT IF CREW IS MAKING RADIO TRANSMISSION UNTIL TRANSMISSION COMPLETED	3.23	1.09	3	4
INCREASE VOLUME	3.35	0.53	3	1
HAVE SYNCALL MAKE NORMAL ALTITUDE CALLOUTS ONLY	3.46	0.97	4	1
WITH THE 50-FOOT CALLOUT, CALL AIRSPEED AND SINK RATE AND ELIMINATE 40,30,20,10-FOOT CALLOUTS	3.54	1.27	4	1

Several of the pilots noted independently that the airspeed deviation callouts in particular were repeated too often and before they could slow the airspeed to within tolerance. They found this to be a nuisance and distraction. This judgment was supported in the rating data on the list of modifications that the pilots suggested for SYNCALL on the de-briefing forms. Of the 31 suggested modifications, "Eliminate Nuisance Callouts" ranked 3rd with a mean of 1.4 on a scale of 1 to 5 for highly desirable to unsafe and had a median response of 1 (highly desirable). The suggestion "Minimize Frequency of Deviation Callouts" ranked 9th out of 31 with a mean of 2.15 and a median response of 2 (desirable). It will be remembered that more pilots in selecting those callouts by SYNCALL that they though useful and desirable, chose normal callouts than did deviation callouts. The perceived nuisance of excessive repetition rates for deviation callouts could possibly explain the smaller percentage of pilots who wanted deviation callouts by SYNCALL compared to those who wanted normal callouts by SYNCALL. There was, incidentally, no correlation between individual pilots' flight performance in each of the four parameters and the desirability of deviation callouts in each of the parameters. If anything, there was a trend for those pilots with greater percent time out of tolerance in a given parameter to be more likely to find deviation callouts for that parameter useful and desirable. The item "Increase Tolerance on Airspeed Deviation Callouts" ranked 7th with a mean of 2.03 and a median response of 2 (desirable). Also, the airspeed tolerance was the only tolerance that the pilots who completed the follow-up debriefing form wanted changed. And the change they recommended was to increase the tolerance on the positive side from +7 to +10 KTS while decreasing the tolerance on the negative side from -7 to -5 KTS.

Summary of Pilot Judgment Data

Clearly the pilots who evaluated SYNCALL generally found the system desirable for some but not all types of approach conditions. They seem to indicate that they would find it a useful aid but would not want to have to use it for every approach. An on/off switch was judged "highly desirable" and "essential" by 10 of the 13 pilots who responded to the suggested modifications. It should be noted here that there were no differences between captains and first officers in the way they evaluated SYNCALL; nor did the particular set of approaches the pilots flew with SYNCALL have any statistically significant effect on their evaluation of the system. This suggests that the pilot judgment data is reliable and that there is considerable agreement among pilots regardless of the position they fly or the specific conditions of the approaches they flew using SYNCALL.

DISCUSSION

Implications of Improved Flight Performance

The results of this study suggest that the concept of synthesized voice approach callouts should be developed further. Flight performance with SYNCALL making the callouts was better during non-precision approaches than when only the current PNF callouts were used. The parameters of flight performance that were better when associated with SYNCALL were airspeed and sink rate. Airspeed (as an input to estimated ground speed) and sink rate constitute the raw data used by a pilot to fly a desired glide-path during a non-precision approach which, by definition, has no direct glide-path information displayed to the pilot. A non-precision approach is considered more difficult to fly just because of the lack of direct glide-path information as compared to the easier precision approach which provides glide-path information displayed directly to the pilot. Thus the use of SYNCALL was associated with improved flight performance for a type of approach that is more difficult to fly.

By comparison data for the precision approaches, showed no statistically significant differences in flight performance as a function of callout system. If SYNCALL were a benefit only for non-precision approaches, what might be the relative gain to airline operations as a whole by the implementation of a properly designed synthesized voice approach callout system?

Non-precision approaches result in a large percentage of the air carrier approach and landing accidents and incidents, 53% according to the NTSB study (1). If a system which improves flight performance for this type of approach in particular made a sufficiently large contribution to lowering the over-all approach and landing accident rate it might pay for its installation. Of course, one would have to consider other solutions as well, including elimination of the non-precision approach from airline operations, different types of cockpit displays, and different types of flight information displayed to the pilots. A comparative cost analysis of such alternatives is beyond the scope of this study.

There is no single reasonable conclusion that can be reached from the experimental observation that SYNCALL was associated with better flight performance only for non-precision approaches - approaches which demand high levels of attention by the PF and by the PNF who is monitoring. It could be that the higher attention workload that is usually but not exclusively associated with non-precision approaches is the underlying factor whose effect could be mitigated by SYNCALL. If this is correct, then SYNCALL would be expected to be helpful during any approach with high attention workload.

Implications of Differential Callout Reliability

The data on PNF and SYNCALL callout reliability suggest that the function of SYNCALL should be to alert the crew to deviations from desired flight parameters but not to make routine callouts. Altitude callout reliability by PNF was comparable to that of SYNCALL. Also 23% of the SYNCALL callouts overlapped crew checklist callouts. In contrast, the PNF minimized this overlap by sequencing altitude callouts between checklist callouts whenever possible. Thus one cannot attribute improved flight performance to any greater reliability of SYNCALL over PNF for routine altitude callouts. And it is possible that SYNCALL altitude callouts actually interferred with pilots' comprehension of checklist callouts. Pilots did, in fact, rate SYNCALL less "coordinating" than PNF. All this argues against automatic altitude callouts by SYNCALL.

The case for deviation callouts by SYNCALL is very different. They were substantially more reliable when made by SYNCALL than by PNF. Also, because they occurred infrequently compared to altitude callouts, their interference with crew checklist callouts would be minimal and thus could be an acceptable price in increased audio workload to pay to the benefit of timely and reliable alerts to flight performance deviations.

Occasionally, however, an altitude callout can function as a warning of an unnoticed deviation. One can speculate that certain airline accidents might not have occurred, had automatic altitude deviation callouts been made (cf. 6 and 7). If a reliable algorithm to detect unnoticed altitude deviations during the approach could be developed, this could be a valuable component of a SYNCALL system. One algorithm for this is proposed for consideration in the section entitled "Refinement of a synthesized voice approach callout system".

Consistent with a SYNCALL system that calls out deviations only would be the incorporation of the Ground Proximity Warning System (GPWS) modes into SYNCALL. SYNCALL as tested included warnings for excessive sink rate and for deviation below the glideslope. The "excessive rate of closure with terrain" mode of the GPWS logically could be added to the set of conditions SYNCALL monitors and calls out.

If this reasoning is correct, a SYNCALL system that automatically called out deviations in airspeed, sink rate, glideslope, localizer, altitude, and terrain closure, only when deviations actually existed, could be a valuable addition to airline cockpit systems.

CONCLUSION

The concept of an automatic approach callout system using synthesized speech definitely deserves further study. Improvements in flight performance by airline pilots were obtained for approaches that have high manual and visual workload for the pilots. By extrapolation, similar improvements might be obtained for any high workload approach. For the One-Engine Approach, for which SYNCALL made inappropriate deviation callouts, airspeed performance was worse with SYNCALL than with PNF. Reliability of normal altitude approach callouts was comparable for PNF on the line and in the simulator and for SYNCALL in the simulator. However, SYNCALL was more reliable than PNF for making deviation approach callouts in the simulator. Pilots generally favored the concept of SYNCALL and judged it more reliable than PNF callouts. They suggested modifications before it would be appropriate for operational use. It was concluded that SYNCALL improved flight performance for non-precision approaches, that a SYNCALL system should make deviation callouts only. For consistency, it is recommended that the modes of the Ground Proximity Warning System (GPWS) be incorporated into a SYNCALL system. The detrimental effects on performance associated with inappropriate deviation callouts led to the further conclusion that such callouts should be designed out of the system. Finally, in the section entitled "Refinement of a synthesized voice approach callout system", the results and conclusions of the experiment are used to develop suggestions for improvements to SYNCALL before further testing.

Clearly the SYNCALL system as configured for this experiment is not appropriate for air transport use. This is evidenced by the fact that some of the data for some of the measures of system effectiveness found SYNCALL to be no better than or, in some cases, not as good as PNF callouts. For example, SYNCALL was judged as more reliable than PNF callouts; but it was also judged less informative, less helpful, and less coordinating than PNF callouts. These pilot rating scale data agreed with the callout system performance data on reliability of the callouts being made. And, the rating data on the scales informative/ distracting, helpful/ detrimental, and coordinating/ disruptive were at least indirectly supported by the data on percent overlap of SYNCALL callouts with other voice communications in the cockpit. Finally, the long list of pilot recommended modifications and the "highly desirable" and "desirable" ratings they assigned to these modifications argue against implementation of the system exactly as configured for the experiment.

What, then, might an appropriate SYNCALL system be like? It is difficult to derive a coherent recommendation for system design from only one type of data. However, when the flight performance data is considered together with the pilot rating data, the callout reliability data, and the percent overlap data, a consistent argument can be made in support of a general design for a synthesized voice callout system with certain variables still undefined or requiring experimental comparison among alternatives. Such a system, once configured, would then have to undergo testing using a methodology similar to that used in this study.

SYNCALL System Components

While SYNCALL was designed as a single experimental system so as to test several different types of synthesized approach callouts, it was composed of different functional parts. These are listed below:

1) normal altitude callouts e.g. 1000 AFL, 500, 400 ...
2) normal position callouts e.g. outer marker, G/S intercept, ...
3) deviation callouts e.g. airspeed +15, left of localizer, ...
4) critical altitude callouts, e.g. decision height, MDA
5) priority logic
6) callout timing and repetition logic
7) tolerance values

The experimental design tested the entire SYNCALL system compared to the entire PNF system of callouts. Thus no conclusions can be drawn from the results regarding the relative contribution of different functional components of each callout system to the observed flight performance, system performance, and pilot rating

TABLE OF CONTENTS

List of Tables..............................iii 1/A7
List of Figures.............................v 1/A9
List of Appendices..........................v 1/A9
Foreward...................................vi 1/A10
Summary..................................viii 1/A12
Introduction................................1 1/A13
Objective...................................2 1/A14
Experimental Approach.......................2 1/A14
Flight Deck Data Collection.................3 1/B1
    Approach and Landing Procedures.......4 1/B2
    ATC Communications Workload by Phase of Flight............8 1/B6
    Overlapping Audio Signals and Voice Communications..........8 1/B6
Synthesizer Callout System (SYNCALL)..........11 1/B9
    System Design.........................11 1/B9
    Voice Message Design..................14 1/B12
Experimental Design..........................16 1/B14
Development of Performance Measures...........19 1/C3
    Percent Time Out of Tolerance.........20 1/C4
    Maximum Deviation.....................20 1/C4
    Mean Positive Deviation...............20 1/C4
    Mean Negative Deviation...............21 1/C5
Flight Performance Parameters.................21 1/C5
    Operational Airspeed Tolerance........22 1/C6
    Operational Sink Rate Tolerance.......22 1/C6
    Operational Localizer Deviation Tolerance....................25 1/C9
    Operational Tolerance for Glideslope Deviations...................25 1/C9
Measures of Pilot Judgments of System Performance............................28 1/C13
Procedure.....................................30 1/D1
Results.......................................33 1/D4
Flight Performance Results....................33 1/D4
    Analyses of Approaches Overall........34 1/D5
    Summary of 4-Way AOV's................42 1/D13
    Analyses of Individual Approaches.....43 1/D14
    Airspeed Deviations During Localizer Back Course Approach..........44 1/E1
    Sink Rate Deviations During the VOR Approach.....................46 1/E3
    1-Engine Approach and Landing Performance..................48 1/E6
    Summary of Individual Approach Results......................51 1/E9
SYNCALL and Pilot-not-Flying Callout Performance...........................43 1/D14
    Reliability of Callouts...............52 1/E10
    Relative Timing of Normal Callouts made by PNF and by SYNCALL....57 1/F1

Other Audio Information that Overlapped SYNCALL Callouts.......58 1/F2
Timing Accuracy of Ten-Foot Callouts by SYNCALL....................59 1/F3
Inappropriate Callouts by SYNCALL.....60 1/F4
Callouts Made by PNF but not by SYNCALL....................60 1/F4
Summary of Callout Performance Data...65 1/F13
Pilot Judgment Data...........................65 1/F13
Summary of Pilot Judgment Data........74 1/G9
Discussion....................................76 1/G11
Conclusion....................................78 1/G13
Refinement of a Synthesized Voice Callout System........................79 1/G14
SYNCALL System Components.....................79 1/G14
Normal Altitude Callouts..............80 2/A3
Normal Position Callouts..............80 2/A3
Deviation Callouts....................80 2/A3
Critical Altitude Callouts............80 2/A3
Priority Logic........................81 2/A4
Callout Timing and Repetition Logic...82 2/A5
Tolerance Values......................83 2/A6
Summary of Recommended Changes to SYNCALL....................84 2/A7
Summary of Proposed Modifications to SYNCALL....................88 2/A11
References....................................89 2/A12

differences. However, analysis of the data was done in a way that permits rational speculation on the contribution of individual SYNCALL components to the observed differences. And the resulting speculations can be used to derive further hypotheses for testing.

When looking for the underlying reasons for the observed differences associated with the two systems, one naturally looks for differences in performance between corresponding components of the two callout systems. Each of the seven system components listed above will be treated in turn.

1) normal altitude callouts Both the PNF and SYNCALL made the altitude callouts reliably. Although reliability of PNF altitude callouts was slightly less (74%) than that of SYNCALL altitude callouts (85%), there were no approaches for either system for which no altitude callouts were made. Neither system was 100% reliable in making altitude callouts since both the PNF and SYNCALL gave priority to calling deviations when faced with a demand for simultaneous altitude and deviation callouts. Furthermore, the reliability of normal altitude callouts made on the line (83%) was nearly equal to that of SYNCALL (85%) when the line callout reliability was adjusted to account for the high percentage of visual approaches on the line. Since both systems resulted in high reliability for altitude callouts, it is difficult to attribute any flight performance differences to any differences in the altitude callout component of SYNCALL versus PNF. Rather than introduce automatic normal altitude callouts when no particular benefit to flight performance would be expected, altitude callouts by SYNCALL if implemented at all ought to be designed as a back-up - i.e. SYNCALL should make them only if the PNF is unable to make them or forgets to make them for some reason. It must be noted, however, that the pilots actually favored altitude callouts by SYNCALL more than they did SYNCALL deviation callouts. The discussion of deviation callouts, callout timing and repetition logic, and tolerance values below may shed some light on this apparent discrepancy.

2) normal position callouts SYNCALL was more reliable than PNF for these callouts.

3) deviation callouts SYNCALL was more reliable than PNF in calling out deviations in airspeed, sink rate, localizer position, and glideslope position: SYNCALL 90%, PNF 49%, where instances of deviations requiring callouts were counted rather than number of callouts since a given deviation could conceivably result in multiple callouts. This difference between the performance of the two callout systems, then, suggests that the deviation callout component of SYNCALL was important to the observed improvement in flight performance with SYNCALL.

4) critical altitude callouts A direct comparison of the two callout systems for this component is not possible because these callouts are required only if the PF has not announced that the runway is in sight by the time the critical altitude (DH or MDA)

is reached. SYNCALL could not detect whether this was the case, so it always called the critical altitudes. Thus a comparison between PNF and SYNCALL for critical callout reliability is not meaningful.

5) priority logic SYNCALL was designed with different priorities assigned to different types of callouts to cover situations when more than one callout was triggered. The criteria used for this priority assignment were 1) Make the most time-critical callout first, and 2) Make only less time-critical callouts afterwards only if they still apply.

Decision height and MDA were judged prior to the experiment to be the most time-critical of all the callouts since the pilot-flying must act immediately on the information conveyed by these callouts so as not to compromise the safety of the approach by descending below minimums when this is not warranted.

The next highest priority was assigned to deviation callouts; and the deviation parameters were ordered within this from higher to lower priority as glideslope, indicated airspeed, sink rate, and localizer.

Lowest priority was given to normal altitude callouts and normal position callouts. Since these by definition were not expected to occur simultaneously, no priorities within these were assigned. In fact, on rare occasions localizer intercept, glideslope intercept, and/or outer marker passage occur simultaneously.

This priority logic had an effect on the reliabilty of different types of callouts made by SYNCALL. The most reliable were the DH and MDA callouts (100%). Next in reliability were deviation callouts (90%). Lowest in reliability for SYNCALL were altitude callouts (83%). The callouts that SYNCALL made most reliably were the ones that were given the highest priority when the system was designed. It is noteworthy that even SYNCALL, which presumably detected 100% of all the callouts that should have been made, did not have time to speak all the callouts in cases where critical altitude and deviation callouts were required.

We have only anecdotal evidence regarding the priority system used by the PNF to decide which of several simultaneously required callouts to make. Very likely it is much more complex than the unidimensional one employed by the SYNCALL system. It probably takes into account a wide range of real world contextual factors such as the type of approach being made, the type of terrain under the approach path, the weather, the wind conditions (above and beyond considerations made in computing the approach speed), whether or not the runway is in sight, and the amount of excursion beyond tolerance when deciding between multiple deviation callouts. Also, the PNF knows that deviations in certain parameters are associated with deviations in other parameters and that correcting one may effectively correct the other. Excessive airspeed and excessive sink rate exemplify this type of association. If one is present, the other may also be present, especially on non-precision approaches. Whether the PNF calls airspeed or sink rate first will depend, then, on many factors. We cannot hope to duplicate the human's priority system so SYNCALL will function as the PNF does because we do not have all the information, properly weighted, that the PNF brings to the situation.

However, it was possible to observe, both on the flight deck and in the simulator, some general patterns of PNF behavior when confronted with the requirement simultaneous callouts. By noting what callouts the PNF made in these situations and when he made them, we can infer something about his priority system.

The PNF employed a different timing strategy than SYNCALL for integrating altitude callouts and deviation callouts. Often a PNF deviation callout was made immediately after a 100-foot callout, presumably to ensure that the 100-foot callout was made on time. SYNCALL, in contrast, called out a deviation as soon as it was detected and postponed any 100-foot callouts that were required during ennunciation of the deviation callout. Further, such an altitude callout was skipped entirely if the postponement would have caused it to be spoken more than 50 feet late. Had SYNCALL employed the strategy used by the PNF, it might have been more reliable for normal altitude callouts with no detriment to deviation callout reliability. This would have been at the expense of SYNCALL's deviation callout timeliness, however.

6) callout timing and repetition logic Callout timeliness is closely linked to callout timing and repetition logic. The PNF strategy seems to be to wait for 100-foot altitude intervals and to call out any deviations at these times, just after making a 100-foot callout. SYNCALL, on the other hand, called a deviation as soon as it detected one and checked again in 5 s. Assuming a 700 FPM rate of descent, the 5-s interval would be the same as checking every 58 feet or about twice the rate of the PNF in terms of altitude loss. For a 1200 FPM rate of descent, which would trigger a SYNCALL sink rate deviation callout, the altitude loss between SYNCALL repetitions would be 100 feet, the same as for PNF callouts. Thus, only when sink rate itself was excessively high was the repetition rate by SYNCALL equivalent to that of PNF. Otherwise, SYNCALL made deviation callout repetitions for glideslope and airspeed twice as often as the PNF would have done. The approximately double repetition rate of SYNCALL deviation callouts compared to PNF callouts is a second difference between the two systems that could have caused the observed flight performance difference in airspeed and sink rate for the non-precision approaches. Whether increased deviation callout reliability or increased callout repetiton rate or some combination of these produced the improvement in flight performance with SYNCALL cannot be determined from the data since the two factors are confounded. The pilots did judge the system to have an unacceptably high rate of nuisance deviation callouts. If a synthesized voice approach callout system were to be designed for

further testing, serious consideration should be given to ways of reducing deviation callout repetition rates to a level that would not be judged a nuisance by the pilots. Nuisance callouts could also be reduced by changing the decision logic for triggering repetitions of a callout for the same deviation. Pilots commented that if they saw that the pilot-flying was in the process of correcting a deviation, they did not repeat it even if the actual value was still outside tolerance. Only if they observed no change in deviation or an increased deviation did they say they would call it again. The SYNCALL localizer and glideslope deviation callout repetition logic was in fact designed in exactly this way. The logic for the airspeed and sink rate deviation callouts was not. That is, SYNCALL made a repetition of the deviation after 5 s if the value was still outside tolerance regardless of whether the pilot was in the process of correcting or not. In addition to changing the rate of deviation callout repetitions, or perhaps instead of changing this rate, a greater reduction in nuisance callouts might be achieved by making the logic for airspeed and sink rate deviation callouts be the same as that used for the localizer and glideslope deviation callouts and that which the pilots report they use: repeat the deviation callout only if no correction is being made. This approach to reducing nuisance callouts would also be consistent with the finding that pilots were satisfied with the repetition rates for each type of deviation callout and yet wanted a reduction in nuisance callouts.

The timeliness of SYNCALL's initial deviation callouts, however, could have been one of the major contributing factors to the improved flight performance with SYNCALL in that deviations un-noticed by the Pilot-Flying were brought to his attention immediately rather than at the next 100-foot interval of descent. Again, the data do not permit direct inference of this conclusion, but serious consideration should be given to preserving this aspect of SYNCALL if future systems are designed for testing.

7) tolerance values SYNCALL was designed with tolerance values that were 25% to 33% greater than the "book" values used by the PNF. This was done in hopes of ensuring that the PNF would continue to watch for and call out observed deviations even when SYNCALL was in use. Instead, the effect of SYNCALL on PNF deviation callout reliability was to reduce it from 49% to 24%. This suggests a potential problem, that of the PNF relying too heavily on SYNCALL to monitor for and make deviation callouts. Perhaps still larger differences between SYNCALL and PNF "book" tolerances would have relegated SYNCALL to more of a back-up role. One would want to see PNF deviation callout reliability at least as good with SYNCALL as without SYNCALL in order to be certain that SYNCALL was not creating a new problem by its introduction. According to the pilot judgment data, the SYNCALL tolerances, particularly for airspeed, may indeed have been too tight.

A future system might be designed with the airspeed tolerances suggested by the pilots: +10 KTS and -5 KTS.

Summary of Recommended Changes to SYNCALL

On the basis of the analysis of the possible contributions of the different components of SYNCALL to the observed improvements in flight performance and in callout reliability, and to the ratings and suggested modifications by the pilots, a tentative SYNCALL system for further testing can be proposed. The system would make deviation callouts in airspeed, glideslope, localizer, and sink rate using the same tolerances for all but airspeed. The airspeed tolerance would be changed to +10 KTS and -5 KTS from V (APPR). This would give the following tolerances:

GLIDESLOPE	+/- 1 1/3 DOTS
AIRSPEED	V(APPR) +10,-5 KTS
SINK RATE	
2000 -1000 AFL	2500 FPM
1000 - 300 AFL	1200 FPM
BELOW 300 AFL	1000 FPM
LOCALIZER	+/- 1/2 DOT

In addition, consideration should be given to including a callout and associated tolerance for VOR course tracking and for Back Course Localizer course tracking. One could use the values suggested by one of the participating pilots as starting points. These were 1 1/2 dots for a Localizer Back Course and 2 dots for a VOR radial as final approach course.

It will be remembered that for the experiment the functions of the GPWS were incorporated into the SYNCALL system on a non-duplicating basis. Any future SYNCALL system ought to include the excessive terrain closure warning of the GPWS for consistency. While not used in this study, the "Sink on Take-off" functional warning of the GPWS would presumably also be incorporated into a modified SYNCALL system. The other GPWS modes, which all are designed to pertain to sink rate and glideslope in various aircraft configurations would be unnecessary because the information they are designed to convey and some additional information as well, e.g. actual sink rate values, aircraft above glideslope, is given by SYNCALL. In support of this merging of GPWS with SYNCALL there is the semantic differential data which indicates that the pilots found SYNCALL to be more informative, more helpful, more dependable, and more coordinating that either the GPWS Whoop Whoop Pull Up or the GPWS Glideslope message. Also, one of the 31 modifications suggested by the pilots was "Eliminate GPWS and Replace with SYNCALL". This item received a mean rating of 2.15 +/- 0.90 and a median response of 2 (desirable).

Merging SYNCALL and GPWS warning functions would provide the pilot with more information, and in particular would state the problem and the degree of the problem. It can be suggested but not tested after the fact that such a system in place of the GPWS system could have alerted the crew of a 727 that accidentally landed short due to unintentional excessive sink rate on an over-water approach despite the triggering of a Whoop Whoop Pull Up message from the GPWS. (6) 9

The repetition logic for the proposed SYNCALL system should have the feature used by the PNF and by the experimental SYNCALL system for glideslope and localizer deviation callouts; once a deviation has been called, it should not be called again unless the deviation is not being corrected. The time interval of 5 s before a recheck of airspeed, glideslope, or sink and 10 s before a recheck of localizer deviation would be expected to work well provided this change of logic is implemented.

The priority assignment of the different deviations was, from highest to lowest, GPWS Terrain Closure, Glideslope, Airspeed, Sink Rate, and Localizer. Some of the pilots and two of the instructor pilots suggested that Sink Rate deviations should be given higher priority than Airspeed deviations. They thought this would be especially useful for the non-precision approaches, for which glide path information is not available. An experimental comparison of these two priority assignments will have to be made using precision and non-precision approaches and measuring flight performance, callout reliability, callout timeliness, and pilot ratings before one can be chosen over the other. Such an experiment should include more extreme conditions of wind, gusts, and wind direction and velocity changes (wind sheer) than was possible in this study.

Once a particular type of deviation had been called, the next highest priority parameter should be checked before the first is checked again. Without this provision, a SYNCALL system could conceivably call one type of deviation while ignoring others until that deviation was corrected.

The proposed SYNCALL system would not make normal altitude callouts. PNF callout reliability both in the experiment and on the line was, for all practical purposes, equal to that of SYNCALL for normal altitude callouts. Looked at the other way, SYNCALL was unable to improve on the performance of the pilot-not-flying for normal altitude callout reliability; in part this was

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9. The GPWS in this accident was of the type that was designed to call out "Whoop Whoop, Pull Up" for any of four different problems: excessive terrain closure, excessive sink rate, sinking on take-off, and flaps or landing gear not in landing configuration. Newer models of this system have been designed to state the actual problem that triggered the warning, partially conforming to the suggestion here to merge GPWS and SYNCALL design features. One can also hypothesize that for the accident referenced above, the use of this other type of GPWS might have prevented the accident.

because SYNCALL placed higher priority than did the PNF on calling out deviations as soon as detected, often to the detriment of SYNCALL normal callout reliability. There exist, however, rare instances when normal altitude callouts by SYNCALL could actually perform the warning function served by the deviation callouts. If for any reason, the crew is not aware of descent to low altitude and the PNF for that reason does not make the normal altitude callouts, SYNCALL could alert them to this by calling out altitudes only on these rare occasions. This could be designed into SYNCALL by having it automatically armed at the start of each approach to make warning altitude callouts as follows:

Callout Wording	AFL Altitude
BELOW 1000 FEET	900 feet
BELOW 500 FEET	400 feet
BELOW 100 FEET	80 feet

These warning altitude callouts would be made by SYNCALL only if an abnormal descent in terms of sink rate was occurring. Abnormal sink rate would be defined as either excessively high or excessively low sink rate. Appropriate values cannot be given here. As a starting point, one could use sink rate in excess of SYNCALL sink rate deviation tolerances or sink rate less than 100 FPM to cover unintentional gradual descents. It must be emphatically stressed that this part of the proposed SYNCALL system is extremely tentative and is derived from general human factors design principles to avoid false alarms and not from the data collected and analyzed in this study. A far better way of obtaining sink rate values to use as activators for warning altitude callouts by a SYNCALL system would be to analyze sink rate histories from a large sample of different types of approaches that were terminated successfully and compare the resulting means and standard deviations to sink rate histories for approaches that resulted in controlled flight into terrain (CFIT). Unless a combination of values could be found that would virtually eliminate false alarms while virtually guaranteeing that all instances of unintentional descent would be called out, such a feature should not be incorporated into an automatic approach callout system such as SYNCALL.

The Ten-Foot normal altitude callouts deserve special mention, however. Unlike the rest of the normal altitude callouts, SYNCALL was definitely more reliable than PNF for these callouts (100% compared to 77%). This was noted independently during and after the simulator session by some of the participating pilots. In some case, pilots said they felt they were late making ten-foot callouts and that the other pilot made the ten-foot callouts late. Also, captains noted that despite a procedural requirement that they make ten-foot callouts as pilot-not-flying, that they as pilot in command felt obliged to look outside the cockpit during the flare and touchdown.[10] Interestingly, there were no differences in ten-foot callout reliability as a function of position flown. Rather, both captains and first officers simply were not as reliable as SYNCALL in making these callouts. Assuming that the timing of SYNCALL ten-foot callouts could be made acceptable, such callouts could be an effective means of normal altitude information transfer at a point in the approach where SYNCALL would not be making deviation callouts. The timing of SYNCALL ten-foot callouts might be improved an algorithm utilizing sink rate to remove the inherent delay in the altitude callout.

For purposes of design consistency and simplicity from the viewpoint of the user, SYNCALL should not make normal position callouts. Even though SYNCALL was more reliable than PNF for this type of callout, inclusion of such callouts in a SYNCALL system would possibly dilute the warning function of the system in that pilots would then not associate SYNCALL callouts strictly with warnings. Also, SYNCALL was not able to make normal position callouts with 100% reliability. This might tend to lessen pilot confidence in the system.

The question of critical altitude callouts (Decision Height, MDA, 100 above MDA) is difficult. On the one hand, these are warnings only if the pilot-flying does not have the runway in sight. If the pilot-flying has announced the runway in sight, then the decision height or MDA callout and Missed Approach Point (MAP) callout will not be needed. The latter would also be extremely difficult to design into a SYNCALL system unless there were access to Inertial Navigation system or RNAV system data. On the other hand, SYNCALL was much more reliable than PNF for these callouts (100% compared to 58%, 48% and 52% respectively for 100 above MDA, MDA, and Decision Height callouts by PNF). In those instances when the decision height callout serves its function and the pilot-not-flying (for monitored approaches) or pilot-flying (for standard approaches) initiates a go-around, it is critical that the callout be made in a timely and reliable fashion. Were a SYNCALL system to make decision height and MDA callouts in a more timely way than the PNF is able to do, it might be useful to have SYNCALL make such callouts for all approaches with the provision that approach procedures be modified to have the pilot-not-flying call out "Going Around" if SYNCALL says Decision Height and the Pilot-Flying has not announced the runway in sight. In the case of MDA, possibly giving the task of calling out MDA to SYNCALL could make the task of monitoring for the MAP easier for the PNF. This entire discussion of Critical altitude callouts by SYNCALL and possible changes to approach procedures is presented here to stimulate further thought on the question and not to advise for or against implementation of critical altitude callouts in any future SYNCALL systems for testing.

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[10]. Sometime after completion of the experimental approaches for SYNCALL and following informal presentation of these comments to the flight training department of the participating airline, the airline's procedures were modified to permit the captain as pilot-not-flying at his discretion to omit the ten-foot callouts.

Summary of Proposed Modifications to SYNCALL

To summarize, it is suggested on the basis of the findings from this study that SYNCALL be re-configured essentially as an approach warning callout system and be merged with the GPWS as one entire system. For the system to be effective, the recommendations to eliminate nuisance alarms will have to be followed. Also the repetition logic will have to be changed. Finally, on the basis of the detrimental effects observed due to inappropriate airspeed deviation callouts during the single-engine approach, no inappropriate deviation or other warning callouts can be tolerated. If these cannot be designed out of the system, or at best designed with a pilot-selectable deactivation switch, then they should not be included as part of it at all. The resulting system will then have to be tested in a flight simulation study similar in comprehensiveness of systems and approach environment to that used for this study.

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ALTITUDE AND APPROACH CALLOUTS BY SPEECH SYNTHESIZER

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In preparation for a flight simulation study of synthesized speech Approach Callouts in an American Airlines DC-10 flight training simulator, phoneme codes for the ML-1 Speech Synthesizer[1] were programmed to develop a Vocabulary of words and short phrases that could be appropriately concantenated to produce all of the required callouts including readout of actual altitude, airspeed, and rate of sink. Callout messages composed from this Vocabulary were then tested for intelligibility.

In order to maximize the chances for misunderstanding of any messages that might be of low intelligibility, the testing conditions were chosen so as to be more difficult than any of the conditions that were expected to actually occur in the flight simulator. Background noise shaped to simulate DC-10 cockpit noise was presented at a level 10 db above the level of the loudest speech segment in the Approach Callout messages. The airline pilots who attempted to understand the callouts were given no prior exposure to the callouts and were told only that the messages they would hear were similar to the callouts made during the approach by the pilot-not-flying. The pilots represented several different airlines and thus were not necessarily familiar with the particular set of callouts or the phraseology used in this study. The results are presented in outline form on page 3. The mean articulation score of 90.4% correct under these extremely difficult testing conditions indicates that this set of callout messages is very intelligible and suggests that these messages would be acceptable for use in the flight simulator.

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[1] Manufactured by Vocal Interface Division, Federal Screw Works, Troy, Michigan

As a further test of the individual words used to compose altitude callouts, a separate study was conducted with messages consisting entirely of altitudes ranging from Flight Level 440 to 10 feet radio altimeter. Two pronunciations of the digits for the altitude callouts were tested, a "phonetic" pronunciation and a "normal" pronunciation. In addition, pilots were asked to give their preferences for type of pronunciation and also for altitude phraseology, e.g. one three thousand versus thirteen thousand for 13000. These results are presented on pages 4 and 5. The high articulation scores of 94.7 to 100% correct at a S/N of -10 db also suggest that these individual words are highly intelligible and adequate for use in the simulator. No significant difference in intelligibility was obtained for the two types of pronunciation. A majority of the pilots, however, preferred the "normal" pronunciation over the "phonetic" pronunciation, except for the digit 9, which a majority of pilots preferred to have pronounced as "niner". Therefore, it is recommended that "normal" pronunciation be used for all digits except "niner". For altitude phraseology, nearly all pilots tested preferred the standard ATC phraseology, e.g. one three thousand for 13000 and one three hundred for 1300. It is therefore recommended that the synthesizer follow ATC phraseology rules in making altitude callouts.

Finally, pilot preferences for speech rate, voice pitch, and signal-to-noise ratio for this synthesizer were obtained. These results are presented on page 6. In general, pilots preferred a voice pitch in the middle of the male voice pitch range with no significant differences in voice pitch or speech rate as a function of presence or absence of cockpit noise. The mean preferred signal-to-noise ratio was 2.4 db. It should be noted that the standard deviation of these preferences was quite large, 7.6 db. In order to accomodate those pilots requiring a high signal-to-noise ratio, it is recommended that the callouts be presented at a signal-to-noise ratio of 8 db, slightly less than the mean + 1 standard deviation.

Approach Callouts at S/N = -10db: Intelligibility in DC-10 cockpit noise

Stimuli: Standard American Airlines DC-10 Approach Callouts presented over headphones with simulated DC-10 cockpit noise as background; S/N = -10 db. Each Callout presented once only. No prior familiarization with the messages.

Subjects: 7 Airline pilots

Results:

Percent Word Articulation for 27 callouts containing a total of 97 words

Pilot Number	Age	Word Articulation = Percent Correct
1	31	90.7
2	34	95.9
3	43	88.7
4	33	100.0
5	39	89.7
6	37	88.7
7	42	79.4
Mean	37	90.4

Phonetic versus Normal Pronunciation: Intelligibility Comparison

Stimuli: Altitude readouts ranging from 10 feet to Flight Level 440 presented over headphones with simulated DC-10 cockpit noise as background; S/N = -10db.

Subjects: 5 airline pilots

Test Material: The "Phonetic" and "Normal" sets contained identical altitudes and differed only in the pronunciation of the digits 3, 4, and 5. The digit 9 was pronounced "niner" in both sets.

Digit	Phonetic Pronunciation	Normal Pronunciation
3	tree [tri]	three [θri]
4	fower [fowɚ]	four [fɔɚ]
5	fife [fajf]	five [fajv]
9	niner [najnɚ]	nine [najnɚ]

Results:

Percent Word Articulation for 2 sets of 24 altitudes containing a total of 171 words

Pilot Number	"Phonetic Pronunciation" Set 1	"Phonetic Pronunciation" Set 2	"Normal Pronunciation" Set 1	"Normal Pronunciation" Set 2
1	96.6	100.0	100.0	97.7
2	94.0	100.0	100.0	100.0
3	100.0	100.0	100.0	100.0
4	83.1	100.0	100.0	100.0
5	100.0	100.0	98.8	100.0
Mean	94.7	100.0	99.8	99.5

Analysis: There was no significant difference in aritculation scores for the two types of pronunciation.

* All data were obtained using a VOTRAX ML-1 voice synthesizer, manufactured by Vocal Interface Division, Federal Screw Works, Troy, Michigan

Airline Pilot Preferences for Pronunciation of Altitude Readouts

Subjects: 12 airline pilots

Results:

Digit	Phonetic Pronunciation	Normal Pronunciation	Either One OK
3	1	10	1
4	3	8	1
5	3	9	0
9	8	2	2

Altitude	ATC Phraseology[+]	Common Phraseology[+]	Either One OK
13000	11	1	0
1300	12	0	0

Numbers are number of pilots responding in each category

Conclusion: A majority of airline pilots prefer normal pronunciation for the digits 3, 4, and 5 and phonetic pronunciation of the digit 9 as niner. They prefer the standard ATC phraseology for altitudes over the Common phraseology, e.g. one three thousand over thirteen thousand and one thousand three hundred over thirteen hundred.

[+] ATC Phraseology = one three thousand and one thousand three hundred
Normal Phraseology = thirteen thousand and thirteen hundred

Airline Pilot Preferences for speech rate, voice pitch, and signal-to-noise ratio for the Votrax ML-1 Speech Synthesizer

Stimuli: Synthesized Altitude and Approach Callout Messages presented over headphones with and without simulated DC-10 cockpit noise as background.

Subjects: Commercial airline pilots

Procedure: For speech rate and voice pitch preferences, each pilot adjusted the appropriate knobs (continuous analog adjustment) first with no noise, then with background noise while listening to the Callout messages repeated 10 times each. For signal-to-noise preferences, pilots told experimentor to adjust the message level up or down until satisfied with the level of the messages relative to the noise level. Experimentor made adjustments in 10, 5, and 1 db units using a calibrated attenuator.

Results:

		Mean		Stand. Dev.		N
		Knob Setting	Measured Freq.	Kb St.	F*	
No Noise	Rate	5.7		± 1.1		13
	Pitch	5.3	91 Hz	± 1.0	+9 Hz -8 Hz	13
With DC-10 Cockpit Noise	Rate	5.6		± 1.3		13
	Pitch	5.6	92 Hz	± 0.5	+7 Hz -3 Hz	13
	S/N	+3.4 db		± 7.6 db		9

* Note: The relationship between units marked on the pitch control knob of the VOTRAX and the resulting fundamental frequency of the synthesized voice is nonlinear.

VOCABULARY OF WORDS AND PHRASES USED TO GENERATE APPROACH CALLOUTS

Item Number	Vocabuary Item
1.	zero
2.	one
3.	two
4.	three
5.	four
6.	five
7.	six
8.	seven
9.	eight
10.	niner
11.	ten
12.	eleven
13.	twelve
14.	thirteen
15.	fourteen
16.	fifteen
17.	sixteen
18.	seventeen
19.	eighteen
20.	nineteen
21.	hundred
22.	thousand
23.	twenty
24.	thirty
25.	forty
26.	fifty
27.	sixty
28.	seventy
29.	eighty
30.	ninety

VOCABULARY ITEMS (cont.)

Item Number	Vocabulary Item
31.	Flight Level
32.	MSL
33.	Above Field
34.	feet
35.	minus
36.	plus
37.	/message-initial pause/
38.	/phrase or message-final pause/
39.	Rate of climb is
40.	You're above the glideslope.
41.	You're below the glideslope.
42.	You are right of the localizer.
43.	You are left of the localizer.
44.	and
45.	Whoop Whoop! Pull Up!
46.	Passing through 18000.
47.	Leaving 11000.
48.	Glideslope intercept.
49.	Localizer intercept.
50.	Outer Marker
51.	Decision Height
52.	100 feet above MDA.
53.	Sink is
54.	MDA
55.	Airspeed

APPENDIX B

Flight Scenario for One of Four Experimental Orders

Captain:
- A. Takeoff
- B. ATC Departure
- C. Holding and/or Steep Turns and/or Stalls (Instructor Pilot's discretion)
- D. Vectors for Approach
  - 1. (SYNCALL) Backcourse 5R (10 KTS cross-wind) with complete missed approach.
    Vectors or reset to:
  - 2. (SYNCALL) ILS DUAL LAND approach and landing (10 KTS cross-wind)
- E. Takeoff Engine Failure between V1 and V2 (no wind)
  Vectors or reset to:
  - 3. (SYNCALL) Two-engine ILS to 100 feet (10 KTS quartering wind) and missed approach.
    Vectors or reset to:
- F. Two-engine landing.

F/O:
- G. Takeoff
- H. ATC Departure
- I. Holding and/or Steep Turns and/or Stalls (Instructor Pilot's discretion)
- J. Vectors for Approach
  - 1. (SYNCALL) Backcourse 5R (10 KTS crosswind) with complete missed approach.
    Vectors or reset to:
  - 2. (SYNCALL) Coupled ILS APPCH ONLY and land (no wind)
- K. Takeoff engine Failure between V1 and V2 (no wind)
  Vectors or reset to:
  - 3. (SYNCALL) Two-Engine ILS to 200 feet and land (10 KTS quatering wind)

L. Takeoff and vectoring for approaches

Captain:
- 4. (PLTNFLY) VOR to 7L/R using Raw Data with rejected landing at 10 feet.(10 KTS crosswind) Vectors or reset to:
- 5. (PLTNFLY) ILS DUAL LAND to SINGL LAND to go-around (10 KTS wind) Vectors or reset to:

F/O:
- 4. (PLTNFLY) VOR to L/R using Raw Data with rejected landing at 10 feet. (10 KTS crosswind) Vectors or reset to:
- 5. (PLTNFLY) ILS DUAL LAND to SINGL LAND to APPCH ONLY and go-around(10 KTS wind)

Captain: M. Engine Failure or shutdown, then:
N. Engine Fire, the Vectors or reset to:
- 6. (PLTNFLY) One-Engine Landing (VFR and no wind)

Notes: SYNCALL = Synthesized Voice Approach Callout System
PLTNFLY = Pilot Not Flying Callout System
The above scenario shows the assigment of pilot-flying and callout system used to Presentation Order 1. Presentation Orders 2, 3, and 4 were derived by altering the pilot to fly first (Captain or First Officer) and the callout system to be used first (SYNCALL or PLTNFLY) The order of the approaches flown: (1, 2, 3, 4, 5, 6) was constant for all Presentation Orders in accordance with American Airlines' recurrent training syllabus.

PILOT EVALUATION OF APPROACH CALLOUT SYSTEMS

The speech synthesizer was programmed to make all of the altitude and deviation approach callouts. This was done to give you a chance to experience the range of capability of such a system. In your own professional judgment, certain types of callouts, either by the speech synthesizer or by the pilot-not-flying, may be more or less desireable.

The next two pages contain "preference grids". The different types of callouts are listed down the side - first for SYNCALL, the speech synthesizer, then (on the next page) for the PILOT-NOT-FLYING. Also 4 different types of approach conditions are listed across the top of each preference grid:

1) Night VFR
2) Abnormal or Emergency
3) Day VFR
4) IFR to Minimums

Starting with the grid for SYNCALL, put a check in the appropriate box for each type of callout that you think would be useful and desireable for the type of approach listed. Do this for each type of approach condition. Then repeat the process for the PILOT-NOT-FLYING grid. Check as many or as few callouts for each type of approach condition and system as you want. If you want no callouts for a particular type of approach and system, check the lowest box, "none".

SYNCALL

	Night VFR	Abnormal/ Emergency	Day VFR	IFR to minimums
Glideslope Intercept				
Localizer Intercept				
OM and Altitude AFL				
1000 Feet AFL				
100 Feet Above MDA				
MDA				
Decision Height				
500 Feet, Airspeed & Sink Rate				
Hundred Foot Callouts				
Ten Foot Callouts				
G/S Deviations				
LOC Deviations				
Sink Rate Deviations				
Airspeed Deviations				
None (no callouts)				

PILOT-NOT-FLYING

	Night VFR	Abnormal/ Emergency	Day VFR	IFR to minimums
Glideslope Intercept				
Localizer Intercept				
OM and Altitude AFL				
1000 Feet AFL				
100 Feet Above MDA				
MDA				
Decision Height				
500 Feet, Airspeed & Sink Rate				
Hundred Foot Callouts				
Ten Foot Callouts				
G/S Deviations				
LOC Deviations				
Sink Rate Deviations				
Airspeed Deviations				
None (no callouts)				

Assume for the moment that the PILOT-NOT-FLYING callouts were modified to be exactly the way you specified in the preference grid. Rate your system on the following scale by placing an "X" in the appropriate space.

________:________:________:________:________:________:________

unsafe — no preference — highly desireable

Now assume for the moment that SYNCALL were implemented exactly the way you specified in the preference grid. Rate your system on the scale below.

________:________:________:________:________:________:________

unsafe — no preference — highly desireable

Now assume the PILOT-NOT-FLYING callouts remain the same as they are now. Rate the current system of pilot-not-flying callouts on the scale below.

________:________:________:________:________:________:________

unsafe — no preference — highly desireable

Now assume that the SYNCALL system were implemented exactly as you experienced it today in the simulator. Rate this system on the scale below.

________:________:________:________:________:________:________

unsafe — no preference — highly desireable

On the next four scales below, rate the intelligibility of the four types of speech which you just heard in the simulator.

SYNCALL

________:________:________:________:________:________:________

0% — 50% — 100%

LA TRACON

________:________:________:________:________:________:________

0% — 50% — 100%

LAX TOWER

________:________:________:________:________:________:________

0% — 50% — 100%

PILOT-NOT-FLYING

________:________:________:________:________:________:________

0% — 50% — 100%

If a SYNCALL system were installed in the cockpit, it might be desireable to build in some limits on the conditions for the different callouts. Listed below are several technologically feasible constraints for such a system. Using the following scale, rate each suggestion by placing a 1, 2, 3, 4, or 5 in front of it.

1 Highly desireable

2 Desireable

3 No preference

4 Undesireable

5 Unsafe

____ Deviation callouts not activated until 500 feet above field and lower.

____ Hundred Foot callouts activated only for coupled approaches.

____ Hundred Foot callouts can be deactivated by Captain at Captain's discretion for VFR approaches.

____ Glideslope deviations can be deactivated at Captain's discretion for VFR approaches.

____ ____

____

____ ____

____

____ ____

____

(In the blank spaces, add any limits that you would want to impose on such a system and rate your suggestions with the same scale.

PILOT RECOMMENDATIONS FOR MODIFICATION OF SYNCALL

Introduction

The tolerance windows for the SYNCALL deviation callouts were picked as "ball park" values so as to test the general concept of an automatic approach callout system. I figured the values might need changing once a group of line pilots had actually flown SYNCALL in the simulator. When you were flying SYNCALL, you may have thought the deviation callouts were made too frequently or maybe not often enough and that the allowances on airspeed, sink rate, glideslope, and localizer were either too loose or too tight to work well in the real world. I would like to get your recommendations for setting the tolerances for each type of deviation callout. And I would like to also get your recommendations for the priority assignments to each type of callout. Please answer each of the following questions based on your short experience with SYNCALL and on your extensive experience flying the line. And feel free to add comments !

If you have any questions about what I'm asking, please call me (collect) at NASA. When you call, just say that you were in the SYNCALL study. When you have finished filling this out you can use the stamped, self-addressed envelope to mail it back to me.

Return to:

Carol A. Simpson, PhD
Mail Stop 239-2
NASA Ames Research Center
Moffett Field, CA 94025

Call collect: 415/965-6128

1. SYNCALL tolerance "windows"

The chart below shows the tolerance "windows" that were set for SYNCALL when you flew it in the simulator. In each case, the "window" is wider than the tolerances you have in your operating manual for the pilot-not-flying and the flight engineer to use when making deviation callouts.

AIRSPEED	Approach ("Bug") Speed	± 7 KTS
SINK RATE	Between 2000 and 1000 AFL	2500 fpm
	Between 1000 and 300 AFL	1200 fpm
	Below 300 AFL	1000 fpm
LOCALIZER		1/2 dot
GLIDESLOPE		1 and 1/3 dot

In the chart below please fill in the values that you think SYNCALL should use. Note that for the airspeed you don't have to choose the same amount on the negative side as on the positive side. For example, you could choose -20 and +3. Keep in mind that you want to avoid nuisance callouts but that you want the system to tell you about anything really dangerous.

If you would not want SYNCALL to make a particular type of deviation callout at all, regardless of the size of the "window", please put a check in the box at the far right of the chart on the line corresponding to that type of callout. Note, for example, that you might want SYNCALL on sink rate for only some but not all the altitudes listed.

TYPE OF CALLOUT		"WINDOW"	✓ IF DON'T WANT THIS TYPE CALLOUT
AIRSPEED	Approach ("Bug") Speed		
SINK RATE	Between 2000 and 1000 AFL		
	Between 1000 and 300 AFL		
	Below 300 AFL		
LOCALIZER			
GLIDESLOPE			

2. Deviation callout repetition rates and "active" segments

The chart below shows the rates at which the different SYNCALL deviation callouts were repeated. For example, airspeed deviations were repeated once every 5 seconds as long as the aircraft remained outside the "window". The chart also shows the point in the approach where each callout became "active". At that point SYNCALL would start checking for that type of deviation. Before that SYNCALL would not make any callouts even if the aircraft was outside the "window". For example, SYNCALL started checking for sink rate deviations at 600 feet AFL. Finally, the chart shows the point where SYNCALL was automatically "turned off" for each type of deviation so as to avoid distractions at low altitude. For example, SYNCALL stops checking for glideslope deviations at 100 feet AFL.

TYPE OF CALLOUT	REPETITION RATE	START CHECKING	STOP CHECKING
AIRSPEED	5 sec.	600 AFL	100 AFL
SINK RATE	5 sec.	600 AFL	100 AFL
LOCALIZER	10 sec.	at LOC CAP	100 AFL
GLIDESLOPE	5 sec.	at G/S CAP	100 AFL

In the chart below, please fill in the values that you think SYNCALL should use for repetition rate, start checking, and stop checking. As on page 1, if you would not want SYNCALL to make a particular type of deviation callout at all, regardless of the repetition rate or the "active" segment, please put a check in the box at the far right side of the chart on the line corresponding to that type of callout.

TYPE OF CALLOUT	REPETITION RATE	START CHECKING	STOP CHECKING	✓ IF DON'T WANT THIS TYPE CALLOUT
AIRSPEED				
SINK RATE				
LOCALIZER				
GLIDESLOPE				

3. SYNCALL Priority System

SYNCALL systematically missed certain callouts for certain approaches due to its priority system and the timing of the callouts. For example, on a VOR 7R Approach, MDA was 436 AFL. So SYNCALL called "100 feet above MDA" at 536 AFL and did not make the 500 AFL callout. If a deviation callout coincided with an altitude callout, SYNCALL made the deviation callout and skipped the altitude callout. The chart on the left lists the types of SYNCALL callouts, including the GPWS Whoop Whoop for Terrain (Mode 2), in their order of priority from highest to lowest. If you would want a different order of priorities, please list the types of callouts in the order you would want in the chart in the middle. If there are any of these callouts that you would not want SYNCALL to make at all, please list them in the chart to the right. If, on the other hand, you like the priorities the way they are, please check the box below the three charts.

	Current Priorities	Your Recommended Priorities	SYNCALL should not make these callouts
↑ high	DH or MDA		
	GPWS Mode 2 (Terrain)		
	Glideslope Dev.		
	Airspeed Dev.		
	Sink Rate Dev.		
	Localizer Dev.		
↓ low	Altitude Callouts		

☐ Leave Priorities as they are

4. Suggested Modifications to SYNCALL

Listed below are all the suggestions given by one or more pilots who flew SYNCALL. Please consider each one and give it a rating using the scale at the top of the list. Put your rating for each suggestion on the line just to the left of that suggestion. For example, if you find a particular suggestion "highly desirable", put a "1" on the line next to the suggestion. If you find it "undesirable", then put a "4" beside it. Do this for each suggestion. After you finish, go back and pick out any and all of the suggestions that for you would be essential in order for you to be willing to accept SYNCALL - i.e. if SYNCALL were not modified according to these particular suggestions, then you would not want it in your airplane.

Note that the list continues on the next page.

RATING SCALE

Unsafe	Undesirable	No Preference or Can't Decide	Desirable	Highly Desirable
5	4	3	2	1

✓ here if Essential	Put your Rating here (1,2,3,4,5)	SUGGESTED MODIFICATIONS TO SYNCALL
☐	____	Have ON/OFF switch in case of erroneous info or distraction from SYNCALL

Suggested Modifications to SYNCALL continued -

RATING SCALE

unsafe	undesirable	no preference or can't decide	desirable	highly desirable
5	4	3	2	1

✓here if essential	Put your rating here (1,2,3,4,5)	SUGGESTED MODIFICATIONS TO SYNCALL
☐	____	Provide Test switch for accuracy check
☐	____	Minimize frequency of deviation callouts
☐	____	Delay callouts during radio transmissions (if possible)
☐	____	Eliminate GPWS & replace with SYNCALL
☐	____	Add a warning in case airspeed gets below Alpha Speed
☐	____	Shorten message wording
☐	____	Speed up SYNCALL's speech rate
☐	____	Eliminate nuisance callouts
☐	____	Add other warnings, e.g. engine fire, loss of cabin pressure, etc.
☐	____	Add immediate action checklist items
☐	____	Provide manual volume control
☐	____	Increase volume
☐	____	Increase tolerance on localizer deviations
☐	____	Increase tolerance on glideslope deviations
☐	____	Increase tolerance on airspeed deviations
☐	____	Spell out SYNCALL and pilot-not-flying responsibilities more clearly
☐	____	At the 50 ft callout, call out airspeed and sink. Then eliminate the 40, 30, 20, 10 callouts by SYNCALL
☐	____	Inhibit airspeed and sink rate deviation callouts during abnormal or emergency approaches
☐	____	Automatically change SYNCALL parameters depending on type of approach
☐	____	Call Localizer Capture, then Localizer Intercept
☐	____	Read out Flight Guidance Mode Annunciators after LAND mode has been armed

(continued on next page)

Suggested Modifications to SYNCALL continued -

RATING SCALE

unsafe	undesirable	no preference or can't decide	desirable	highly desirable
5	4	3	2	1

✓here if essential   Put your rating here (1,2,3,4,5)

☐ ____ Call out "Below MDA" if aircraft descends below MDA (unless pilot has pressed a "disable" switch)

☐ ____ On non-precision approaches, give sink rate deviations top priority

☐ ____ Obtain FAA & Company agreement not to use CVR recordings of SYNCALL against the crew

☐ ____ Have SYNCALL call the flaps setting at 1000 AFL

☐ ____ Have SYNCALL say "Check Flaps" at 1000 AFL

☐ ____ Make voice quality for deviations more alerting compared to altitude calls

☐ ____ Have SYNCALL make deviation callouts only (i.e. only if something's wrong)

☐ ____ Have SYNCALL make altitude callouts only (leave deviations to pilot-not-flying and flight engineer)

☐ ____ If aircraft balloons on landing, have SYNCALL repeat 10-foot callouts as appropriate, e.g. "50, 40, 30, 20, 30, 20, 10"

5. Background Data

Please fill in the chart below only for the type aircraft you were current in at the time that you flew SYNCALL

TYPE AIRCRAFT	POSITION FLOWN	APPROX. NO. HOURS IN TYPE

6. Preference Grids for desired callouts for different types of Approach Conditions

The two preference grids below are like the ones you filled out after flying SYNCALL in the simulator. Please fill them out using the same instructions as before. That is, put a check in the appropriate box for each type of callout that you think would be useful and desirable for the type of approach listed. Do this for each of the four types of approach conditions. By leaving a box blank, you are saying you don't want that type of callout for that type of approach or that you are not sure that you would want it. Check the box only if you really would want SYNCALL to make that callout for that type of approach.
There are two preference grids. Fill out the one on the left assuming SYNCALL stayed the way it was when you flew it in the simulator. Then fill out the one on the right assuming SYNCALL was changed according to your own recommendations on the preceeding pages of this evaluation.

USE THIS GRID FOR SYNCALL THE WAY IT WAS WHEN YOU FLEW IT IN THE SIMULATOR

	Type of Approach Conditions			
Type of Callout	Night VFR	Abnormal/ Emergency	Day VFR	IFR to minimums
Glideslope Intercept				
Localizer Intercept				
OM and Altitude AFL				
1000 Foot AFL				
100 Foot Above MDA				
MDA.				
Decision Height				
500 Foot, Airspeed & Sink Rate				
Hundred Foot Callouts				
Ten Foot Callouts				
G/S Deviations				
LOC Deviations				
Sink Rate Deviations				
Airspeed Deviations				
None (no callouts)				

USE THIS GRID FOR SYNCALL THE WAY IT WOULD BE IF IT WERE CHANGED THE WAY YOU HAVE RECOMMENDED IN THIS EVALUATION

	Type of Approach Conditions			
Type of Callout	Night VFR	Abnormal/ Emergency	Day VFR	IFR to minimums
Glideslope Intercept				
Localizer Intercept				
OM and Altitude AFL				
1000 Foot AFL				
100 Foot Above MDA				
MDA.				
Decision Height				
500 Foot, Airspeed & Sink Rate				
Hundred Foot Callouts				
Ten Foot Callouts				
G/S Deviations				
LOC Deviations				
Sink Rate Deviations				
Airspeed Deviations				
None (no callouts)				

That's the end. Thank you very much, and I'll let you know how this all turns out.

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15. Supplementary Notes

Ames Technical Monitor: Thomas Wempe
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Final Report

16. Abstract

A flight simulation experiment was performed to determine the effectiveness of synthesized voice approach callouts for air transport operations. Flight deck data was first collected on scheduled air carrier operations to describe existing pilot-not-flying callout procedures in the flight context and to document the types and amounts of other auditory cockpit information during different types of air carrier operations. A flight simulation scenario for a wide-body jet transport airline training simulator was developed in collaboration with a major U.S. air carrier and flown by three-man crews of qualified line pilots as part of their normally scheduled recurrent training. Each crew flew half their approaches using the experimental synthesized voice approach callout system (SYNCALL) and the other half using the company pilot-not-flying approach callout procedures (PNF). Airspeed and sink rate performance was better with the SYNCALL system than with the PNF system for non-precision approaches. For the one-engine approach, for which SYNCALL made inappropriate deviation callouts, airspeed performance was worse with SYNCALL than with PNF. Reliability of normal altitude approach callouts was comparable for PNF on the line and in the simulator and for SYNCALL in the simulator. However, SYNCALL was more reliable than PNF for making deviation approach callouts in the simulator. Pilots generally favored the concept of SYNCALL and judged it more reliable than PNF callouts. They suggested modifications before it would be appropriate for operational use. It was concluded that SYNCALL improved flight performance for non-precision approaches, and that a SYNCALL system should make deviation callouts only. For consistency, it is recommended that the modes of the Ground Proximity Warning System (GPWS) be incorporated into a SYNCALL system. The detrimental effects on performance associated with inappropriate deviation callouts led to the further conclusion that such callouts should be designed out of the system. Finally, the results and conclusions of the experiment are used to develop suggestions for improvements to SYNCALL before further testing.

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